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DOT/FAA/PM-87/9, II

Criteria for Coal Tar Seal Coats

Advanced System Design Service
Washington, D.C. 20591

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Federal Aviation Administration
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16. Abstract

Because coal tars are resistant to gasoline and jet fuel, they have been used for many years as a protective coating on asphalt pavements for airport parking areas, ramps, taxiways and runways. Applications include both coal tar emulsions and rubberized coal tar emulsions, applied with sand to provide skid resistance and stability to the seal coats.

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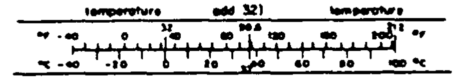
METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ABSTRACT

Because coal tars are resistant to gasoline and jet fuel, they have been used for many years as a protective coating on asphalt pavements for airport parking areas, ramps, taxiways and runways. Applications include both coal tar emulsions and rubberized coal tar emulsions, applied with sand to provide skid resistance and stability to the seal coats.

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Results of the state-of-the-art review, Volume I, indicated that problems with scuffing, cracking, poor friction characteristics, poor adhesion, and poor construction control are often encountered in actual practice.

Most coal tar sealers used on airport pavements are sold as proprietary products. Formulations, type of additive, and sand loadings vary, and optimum formulations are not agreed upon by all suppliers.

The survey indicated that there was a need to develop test procedures that could be used to design seal coat formulations and that could be used for construction quality assurance purposes.

The laboratory study revealed that incompatibilities exist between coal tar an latex additives, which must be taken into consideration when formulating coal tar emulsion seal coats. The type and amount of latex additive was a highly significant factor in producing satisfactory seal coat formulations. The amount of water also was significant. Sand quantity was more significant than sand type or gradation, but less significant than the amount of water and latex.

A mix design procedure, which included measures of workability, rate of set, resistance to scuffing, cracking, adhesion, and fuel resistance, was developed and is recommended for publication, and trial use.

A relatively simple test procedure that measures viscosity was developed and recommended for use as a construction quality assurance test, along with the placing of a test section as currently provided for in FAA item P-625, and the taking of test samples for use if necessary.

It is expected that the results of this study will result in changes in Item P-625 and an improvement in the quality of coal tar emulsion seal coats constructed on airport pavements.

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CRITERIA FOR COAL TAR SEAL COATS
ON AIRPORT PAVEMENTS

FINAL REPORT
Volume II

CHAPTER I INTRODUCTION AND BACKGROUND

INTRODUCTION

It has been observed that under certain circumstances coal tar emulsion seal coats meeting FAA P-625 specifications have exhibited signs of scuffing, cracking, premature aging and reduced service life. This study was designed to obtain information on the performance of these fuel resistant coatings from various agencies, including FAA, aviation authorities and industry representatives; and to conduct laboratory and field studies to determine if P-625 mix formulations and construction guidelines should be modified to produce better performance.

Coal tar emulsion seal coats are composed of coal tar pitch emulsions, water, sand, and, in most cases, latex rubber additives. Coal tar sealers are used to provide fuel resistant coatings on parking lots and airports paved with asphalt concrete, to improve appearance, to protect the pavement from oxidation and weathering, as a maintenance surface treatment, and to renew old, weathered asphalt concrete pavement surfaces.

Coal tar alone has poor skid resistance properties, and sand is added to improve friction characteristics. Sand also is added to increase yield and to improve resistance to cracking and scuffing. Rubber latex additives are used to increase viscosity of coal tar emulsion sealer formulations that contain more than 4 to 5 percent sand, to suspend the sand in the mixture, and to increase flexibility of the coating.

Most coal tar emulsion sealer applications make use of proprietary formulations. FAA Item P-625 is used as the basis for applications on civil aviation airport pavements. FAA Item P-625 requirements are summarized in Table 1.

SCOPE OF THE STUDY

The major objective of this study was to update or develop new materials and construction criteria for the use of coal-tar-rubber-sand coatings on airport pavements. The criteria were to consider the effects of proportions and characteristics of coal tar emulsion seal coats on performance, the effects of water, temperature variations, and exposure to sunlight.

Table 1 FAA Item P-625 Coal Tar Pitch Emulsion Seal Coat Formulations

Type of Seal Coat	Composition and Quantities			
	Water (1) gal/gal of emuls.	Sand (2) lbs/gal of emuls.	Rubber (3) gal/gal of emuls.	Application Rate gal/sq yd (Per Appliction)
Rubberized Sand Slurry	0.70 - 1.00	6 - 14	0.07 - 0.12	0.25 - 0.55
Rubberized Emulsion	0.70 - 1.00	---	0.03 - 0.05	0.10 - 0.25
Sand Slurry	0.10 (max)	5 - 7	---	0.15 - 0.25
Emulsion	0.10 (max)	---	---	0.10 - 0.15

(1) Coal tar pitch emulsion meeting Federal Specification R-P-355 except that water content does not exceed 50 percent.

(2) Sand Gradation

Sieve No.	Percent Passing
16	100
20	85-100
30	15-85
40	2-15
100	0-2

(3) Copolymer latex containing 51-70 parts butadiene and 30-40 parts acrylonitrile for styrene. Up to 3 percent silicones is permitted. Average particle size between 300 and 1500 angstroms.

The scope of the study was to include a review of the literature and current specification, collection and analysis of laboratory and on-site data, together with airport pavement performance monitoring. Work was to include the development of guide specifications to determine optimal proportions of water, sand and rubber in suspension that will effect and extended service life.

The scope also included evaluation of various types of latex rubber for compatibility with coal tar emulsions and the ability of these types to suspend adequately sand loadings up to 16 lbs. per gallon.

Construction procedures such as rate of application, lay down temperatures, and equipment to be utilized were also part of the scope of the project, as were the development of laboratory and field tests for evaluating techniques, and the comparison of the service life of the recommended coal tar emulsions with conventional seal coats for various airport applications.

STUDY PLAN

The project was conducted in three phases: (1) a state-of-the-art review, (2) a laboratory test program, and (3) field test installations.

The results of these three activities are summarized in the following chapters of this report.

Information for the state-of-the-art report was obtained through searches of the literature and through personal contacts with industry and user agencies. An extensive laboratory study was conducted at the University of Nevada at Reno. This study included investigations into the characteristics of coal tar emulsion seal coat formulations and the development of test procedures that can be used for mix design and quality assurance purposes. The field studies were designed to supplement the laboratory studies and to provide field performance data. In addition, the field sites provided an opportunity for comparing formulations of various types, mixed and placed by suppliers to similar mixes deigned by the research staff.

FINAL REPORTS

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The following sections of this chapter include background information on coal tar emulsion seal coats, uses, advantages, disadvantages, major distress types, and results of research by other agencies.

USE OF COAL TAR EMULSION SEAL COATS

Coal tar emulsion sealers historically have been used to protect asphalt pavements from fuel, oil, and water damage. Because they are fuel and oil resistant, they have been used extensively on airport taxiways and fueling areas, and on automobile parking lots, where motor oil drippage can soften an asphalt pavement and cause raveling and stripping. Coal tar sealers also can help prevent the weathering of an asphalt pavement by protecting it from water, sunlight, and oxidation.

Sands are used with coal tar emulsions to enhance their skid resistant properties. The level of skid resistance is influenced by the gradation, amount, and the shape of the sand. Sand loadings (i.e. quantities) have been increased in recent years in an attempt to expand the use of coal tar emulsion sealers by providing thicker and more flexible coatings. However, this increase has resulted in problems with keeping the sand in suspension in the coal tar emulsions, and potentially reduced resistance to fuel spillage.

Experimentation found that the use of latex polymeric additives in the coal tar emulsion could increase its ability to hold the sand in suspension (35,36)*. In addition the latex was expected to increase the flexibility of the sealer, allowing the sealer to move with the underlying pavement as it contracts and expands.

Coal tar sealers have been used successfully for many years; however, on occasion unacceptable field performance has been experienced. Interviews with manufactures, suppliers, contractors, and owners have identified problems (33) with poor workability, reduced skid resistance, cracking, peeling or debonding, and poor fuel resistance.

COAL TAR EMULSION SEAL COAT FORMULATIONS AND SPECIFICATIONS

Raw coal tar is produced from bituminous coal during the manufacturing of coke. Coal tar pitch is formed as a residue from the distillation of the raw coal tar (28).

*Numbers refer to citations in the Bibliography.

Coal tar emulsions are classified as clay emulsions, generally consisting of:

30 - 35% coal tar pitch
20% clay, including bentonite
45 - 50% water.

There are three general categories of coal tar emulsions: the grade meeting Federal Specifications R-P 355(16) containing approximately 54% residue; the domestic grade, cut back with water to approximately 47% residue; and the low residue grade with 35% or less solid residue. The grade meeting Federal Specification R-P 355 is used for the pavement sealers that are considered in this research. Up to 10% latex rubber may be added to retard weathering and cracking, and up to 16 lbs. of sand per gallon of sealer may be added, usually at the job-site, to improve skid resistance properties. They may be winterized by adding a glycol anti-freeze preparation.

ASTM D 3320, Standard Specification for Emulsified Coal Tar Pitch (Mineral Colloid Type) (7) is often used, but is considered by many experts consulted to permit too low residue content for airport applications. Minimum residue contents indicated by the specifications cited are:

ASTM D 3320	42%
R-P-355	47%
P-625	50%

FAA requirements for coal tar emulsion seal coats, with or without rubber latex additives or sand, are included in AC 150/5370-10 CHG 20, Item P-625 (15). Formulations permitted by P-625 are summarized in Table 1.

U.S. Air Force guide specifications for airfield pavements, "Guide Specification for Coal Tar Pitch Emulsion Protective Seal Coat (For Airfield Pavement)" (11) and "Guide Specification for Coal Tar Pitch Emulsion Sand Slurry Seal Coat for Airfield Pavements" (12), contain information pertinent to this study. Air Force specifications permit formulations that will support 5 to 6 lbs of sand; and in many cases this will provide sufficient skid resistance properties. FAA Item P-625, FAA AC 150/5370-10 CHG 20, permits sand loadings up to 14 lbs, and a recent draft modification permits up to 16 lbs of sand per gallon of emulsion (14).

It is generally conceded that sand is required to impart skid resistance properties to coal tar emulsion sealers. Differences of opinion arise over the quantity of sand, sand gradation and type of sand to be used. Table 2 shows several different gradation ranges that indicate the major differences between sand gradations used in coal tar emulsion seals. FAA Item P-625 permits use of sand loadings up to 14 lbs per gallon of emulsion. Some suppliers argue that not more than 8 lbs are required to provide skid resistance, and that higher rates decrease fuel resistance of the coatings.

Table 2 Aggregate Gradations

Sieve Size or No.	Percent Passing by Weight		
	FAA P625 & Air Force Guide Specs.	(1)	(2)
No. 16 (1.18 mm)	100	100	
No. 20 (0.85 mm)	85-100	95-100	
No. 30 (0.60 mm)	15-85	5-15	98-100
No. 40 (0.40 mm)	2-15	1-5	90-98
No. 50 (0.30 mm)			44-75
No. 100 (0.15 mm)	0-2	0-2	5-24
No. 200 (0.074 mm)			0-3

(1) Proposed in FAA Engineering Brief No. 22 (14).

(2) Recommended by some suppliers. (Note, this is a range, not a typical gradation).

A number of additives to the basic P-355 coal tar emulsion are used, or have been proposed, to improve their use as seal coats for airport pavements. FAA Item P-625 permits the use of a latex additive containing 51-70 parts butadiene and 30-49 parts acrylonitrile with the possible addition of a silicone up to 3% of the rubber content. The rubber additives are added to increase the life of these coatings and to permit use of higher sand loadings. Silicones are added to provide better handling characteristics and to provide longer life. The particle size of the latex has been cited as an important factor in supporting high sand contents. Other polymers have been proposed by manufacturers to provide additional improvements, and the use of chemical emulsifying agents to reduce or eliminate the use of clay has been proposed.

ASTM is considering a proposed Standard for aggregate filled pavement sealers, "Performance Standard for Coal Tar Pitch Emulsion Pavement Sealer Mix Formulations Containing Mineral Aggregates and Optional Polymeric Additives". This proposed standard differs from the FAA and Air Force Specifications cited above in that it is based on the use of performance tests instead of prescribed formulas to control mix properties. The proposed standard could be applied to samples of coal tar emulsion sealers both in the formulation stage, and as a post-construction test on samples collected on the job-site.

Construction procedures are considered critical. The US Air Force specifications (11,12) have been cited as sources of good construction practice. It was recommended that a light coating of diluted emulsion be applied as a first coat to be followed after drying by an emulsion sand coat. The Air Force Guide Specification recommends an initial spray coat followed by two or three sand coats.

Good construction practice also may require that the raw pavement be damp or be primed with a light appliction of emulsion when the initial coat is applied. Most important is the cure period between coats and before traffic is allowed to use the pavement. Periods not less than 4 hours and up to 24 hours may be required; although this could create problems with air traffic interruptions. Construction quality control procedures are not well established, and construction control test procedures are not available. Usually, subjectively defined characteristics, such as color and tackiness, are used for construction quality control purposes.

ADVANTAGES AND DISADVANTAGES OF COAL TAR SEAL COATS

Coal tar sealers have traditionally been marketed as proprietary products and, except for Federal and ASTM specifications, have not been the subject of extensive technical discussions as have other bituminous products. Major companies discontinued marketing coal tar emulsions during the oil embargo of the early 70's. However, the products are available from several sources at this time.

Coal tars, in some respects, are similar to asphalts, but they are more temperature susceptible than asphalts, and require some modifications

in construction procedures. However, they are less permeable, provide a better seal, and, particularly, have good resistance to fuel spillage.

Coal tar emulsions have been reported to have good storage characteristics, are easy to make, and are relatively simple to handle and apply, when formulated for home use. They are petroleum and water resistant. Disadvantages include embrittlement and cracking with time, poor adhesion characteristics, poor resistance to traffic and wear on the surface of pavement exposed to heavy traffic, and poor skid resistance, except in the form of a sand slurry.

Coal tar weathers differently than asphalts. Asphalts weather through the effects of oxidation and sunlight, whereas coal tar appears to weather through the evaporation of oils (26). Coal tar emulsions also differ from asphalt emulsions in that coal tar emulsions cure by water evaporation. Thus, curing time is influenced by humidity and similar environmental factors.

MAJOR DISTRESS TYPES

Major forms of distress associated with the use of coal tar emulsion seal coats include cracking, loss of adhesion or wear, and low friction values. Some of the factors involved in distress are listed below.

Cracking

1. Incompatibility between certain asphalts and coal tar
2. Shrinkage of the underlying pavement
3. Shrinkage and brittleness of the coating
4. Sand content
5. Thickness of application
6. Lack of prime coat

Poor-Adhesion

1. Poorly cleaned surface of pavement before sealing
2. Mix proportions not correct
3. Poor mixing and placement (construction)
4. Type of latex additive

Low Friction Values

1. Sand loading
2. Type of sand
3. Type and application rate of top coat
4. Use of silicone

Poor Fuel and Water Resistance

1. Cracking
2. Application rate
3. Sand loading

MATERIAL PROPERTIES

Major problems with coal tar sealers presented above indicate that there are certain desirable properties of coal tar sealers that need to be optimized. The properties that were given major consideration in this study include:

1. Workability
2. Skid resistance
3. Resistance to cracking
4. Resistance to loss of adhesion to the pavement
5. Fuel resistance

Major references to these properties and how they might be measured are discussed in the following paragraphs.

Workability

Workability of a coal tar emulsion sealer can be related to the rheology or viscosity of the mixture. Rheology is defined as "the study of the change in form and the flow of matter embracing elasticity, viscosity, and plasticity" (9). Viscosity is the internal friction of a fluid which causes resistance to flow; shearing is required to overcome the internal friction. Coal tar emulsions exhibit a decrease in viscosity with time, while being subjected to constant shearing. This is known as thixotropy.

Bailey and Croad (8) developed a method to measure the viscosity of paint, a thixotropic material, using a Brookfield Viscometer to perform the viscosity testing. To get reproducible results on thixotropic materials, Bailey and Croad developed a procedure which includes shearing the sample with an agitator prior to taking a viscosity measurement. After shearing, the viscosity of the sample is measured at time intervals to show the period required to recover the original viscosity.

Pierce (28) found the same problem while characterizing the rheological properties of pseudoplastic and thixotropic coatings. Pierce devised a method similar to that of Bailey and Croad, except that the viscosities were taken before, as well as after, the shearing of the sample. If the material does not exhibit time-dependent effects, then the viscosity at a given shear rate is the same before and after shearing the sample. If the material is thixotropic, then the viscosity of the sheared sample will be less than the unsheared sample.

Skid Resistance

Skid resistance studies using the Mu-meter have been performed in Wisconsin, Louisiana, Michigan, Tennessee, and Texas (34). These studies were performed on several types of roadway surfaces, including coal tar emulsions. While wet friction values were lower than dry values for all pavements, there was no indication that coal tar emulsions always produce substantially lower friction values than other pavement surfaces.

Cracking

A review of the literature failed to uncover any information on the cracking of coal tar sealers on asphalt concrete pavements.

Adhesion

Arthur D. Little Laboratories evaluated the adhesion characteristics of coal tar sealers over time (34). Various latex, water and sand contents were employed, and were applied to aluminum panels, and placed in a weatherometer. Three tests were performed: the cross hatch, the mandrel bend, and the ball drop tests. These tests indicated that the rate of failure of the sealers was a function of the sand loading.

Fuel Resistance

The U.S. Army Corps of Engineers, Waterways Experiment Station, has investigated fuel-resistant pavement sealers. Reports released in 1983 and 1984 (32,33) dealt with protecting porous friction surfaces (PFS) with fuel resistant sealers and the construction of new PFS with fuel resistant binders. The "porous friction surface" consisted of "an open-graded, free-draining, bituminous mixture used to prevent hydroplaning, water splashing, and loss of wet traction". The sealers were exposed to permeability tests, hydraulic fluid, fuel-drip, and abrasion tests, which were developed or modified at the Waterways Experiment Station.

A permeability test was developed to insure that the permeability of the sample was preserved. If, after sealing the sample, the permeability fell below a required value, then the coating was considered unacceptable.

The hydraulic fluid test consisted of placing a sealed specimen, with the PFS side down, in 0.5 inch of hydraulic fluid. The sample was examined at predetermined time intervals for visual evidence of damage.

The fuel-drip test involved dripping jet fuel on an asphalt concrete sample coated with coal tar emulsion for 10 minutes at 5 psi. The sample was rotated every 2.5 minutes to insure uniform coverage by the fuel.

The abrasion test was adapted from ASTM D 3910, "Design, Testing, and Construction of Slurry Seal" (2). The test included taking a sample, approximately 30 minutes after completion of the fuel-drip test, and subjecting it to mechanical abrasion testing. The damage caused by abrasion is measured as the weight lost after abrasion.

Several sealers were found to perform favorably when exposed to permeability, hydraulic fluid, fuel-drip, and abrasion testing. These materials included an epoxy resin, a coal tar epoxy, and a rubberized adhesive.

The second research program conducted by the Waterways Experiment Station (WES) in 1984 focused on the further development of test procedures to evaluate fuel resistance of sealers used on dense graded

asphalt concrete (13,32). The procedure relies on the test developed in 1983, and consisted of dripping fuel on a sample of sealed asphalt concrete, followed by an abrasion test. In general the 1984 report found that the coal tar epoxy used in the aforementioned study was superior to coal tar emulsion and plasticized sulfur.

MATERIAL PATENTS

A number of patents cover the additives and formulations used in coal tar sealer mixtures. The Schuler patent (30) introduced a mixture of coal tar emulsion (70 to 91 percent), a neoprene (2 to 6 percent), and fly ash (7 to 25 percent). With materials in these proportions, the mix provides a way to damp-proof a structure, seal a bituminous concrete surface, or protect a structure against penetration of an aqueous radioactive material. The coal tar provides the water-proofing seal, the neoprene increases the flexibility of the coating, and the fly ash adds several superior properties as reported by Schuler. These properties include that, while in the application or wet phase, the fly ash does not increase the viscosity, so the mix is easy to apply. After the material has dried, the fly ash adds skid resistance. Schuler also claims that the addition of fly ash increases the strength and toughness of the sealer. This increase in strength results in greater adhesion, as reported by Schuler, who used the Hoffman Scratch-Hardness Tester to measure hardness and adhesion properties. The patent does not mention how the sealer was tested for skid resistance.

Patents by Walaschek (36,37) define a prescribed mix of water, aqueous coal tar emulsion, copolymer latex, and coarse sand. Walaschek claims this mix retains sufficient viscosity to prevent significant settling of the sand. The coal tar emulsion contains approximately 33 percent coal tar, 22 percent mineral clay, and 45 percent water. The copolymer used was an acrylonitrile (30-49 parts)/butadiene (51-70 parts) latex. Walaschek suggests that a latex with a particle size of 400-1000 angstroms (1 angstrom = 1×10^{-4} microns) provides the coal tar emulsion the ability to hold a high quantity of aggregate in a "matrix-like" suspension, and that the "extraordinarily small particle size" of the latex allows for better distribution of the latex particles in the coal tar emulsion mixture. Coarse sand is considered as "substantially" all sand passing the number 20 sieve and 5 percent by weight passing the number 30 sieve. The quantity of sand is 12 to 18 lbs. per gallon of coal tar emulsion. The ratio of coal tar to water should be about one to one.

Hergenrother (20) patented a mix of coal tar emulsion, water, butylacrylate emulsion, and sand. The amount of water is equal to 0.5 to 1.5 the volume of coal tar emulsion. The butylacrylate emulsion is present from 0.5 to 1.0 percent by weight of total mix (coal tar emulsion and water). The quantity of sand is one to six lbs. per gallon of original coal tar emulsion. The patent claims that this mix had better adhesion and wear characteristic than the original coal tar emulsion. The original coal tar emulsion did not contain butylacrylate emulsion.

Hergenrother believes that there is a close relationship between the quantity of sand and the quantity of coal tar emulsion to be used. If the quantity of sand exceeds the recommended relationship, there will not be enough coal tar to bind the sand particles to each other and to the pavement.

INDUSTRY CONCERNS

In addition to the problem areas already discussed, Shook (34) reported that sand gradation, sand loading (quantity), and latex particle size are issues about which some suppliers of coal tar emulsion disagree. He also concluded that there appears to be major disagreements among industry suppliers on the desirable formulations of coal tar emulsion seal coats. There also appears to be concern about the adequacy of the Federal Aviation Administration (FAA) specification P-625 to insure that a product will perform adequately in the field. Some suppliers believe that coarse sand in the mixture has a tendency to become dislodged from the sealer when subjected to traffic and tends to damage spray bar nozzles. On the other hand other suppliers suggest that the coarse sand gives the seal coat added flexibility, adhesion, and fuel-resistant characteristics.

Another area of disagreement is the sand loading or quantity in the coal tar mixture. One supplier recommends use of up to 16 to 18 lbs. of sand per gallon of coal tar emulsion, while other suppliers believe that 8 to 10 lbs. of sand per gallon of coal tar emulsion is sufficient. They feel the lower sand loadings should be used to insure adhesion between sand particles and the coal tar. This issue is also addressed by Hergenrother (20).

The issue of latex particle size is another concern of the suppliers. The Federal Aviation Administration (FAA) specification P-625 allows an average latex particle size of 300 to 1500 angstroms. One supplier is concerned that a particle size over 1000 angstroms causes the coal tar emulsion to "conglomerate", while latex particle less than 1000 angstroms allow the seal coat to support more sand.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

Results of the state-of-the art review indicated that problems with scuffing, cracking, poor friction characteristics, poor adhesion, and poor construction control are often encountered in actual practice.

Most coal tar sealers used on airport pavements are sold as proprietary products. Formulations, type of additive, and sand loadings vary, and optimum formulations are not agreed upon by all suppliers.

The survey indicated that there was a need to develop test procedures that could be used to design seal coat formulations and that could be used for construction quality assurance purposes.

The laboratory study revealed that incompatibilities exist between coal tar and latex additives, which must be taken into consideration when

formulating coal tar emulsion seal coats. The type and amount of latex additive was a highly significant factor in producing satisfactory seal coat formulations. The amount of water also was significant. Sand quantity was more significant than sand type or gradation, but less significant than the amount of water and latex.

A mix design procedure, which included measures of workability, rate of set, resistance to scuffing, cracking, adhesion, and fuel resistance, was developed and is recommended for publication and trial use.

A relatively simple test procedure that measures viscosity was developed and recommended for use as a construction quality assurance test, along with the placing of a test section as currently provided for in FAA Item P-625, and the taking of test samples for use if necessary.

A more extensive presentation and discussion of the study findings and their limitations are included in a later section of this report. It is expected that the results of this study will result in changes in Item P-625 and an improvement in the quality of coal tar emulsion seal coats constructed on airport pavements.

CHAPTER II LABORATORY AND FIELD TESTING PROGRAM

SCOPE OF LABORATORY AND FIELD STUDIES

A major proportion of the effort in this study was devoted to an extensive laboratory study of the properties of coal tar emulsion seal coats. The studies were conducted at the University of Nevada at Reno (UNR), and included both laboratory experiments and related field test sections. Field sections were installed on a campus parking lot and at a local general aviation airport. The UNR program consisted of the following parts.

Initial Field Test Installations- Initial field test installations provided an opportunity for suppliers of coal tar emulsion sealers to place their recommended formulations, and for the University research staff to develop a first-hand knowledge of the materials. In addition, materials and material quantities placed in the field were used as the basis for selecting materials and quantities to be included in the laboratory testing program.

Phase 1 Laboratory Program- Phase 1 of the laboratory test program was designed to determine materials properties and to evaluate potential test procedures. The program also was used to screen out those test variables that had only a small influence on seal coat properties. Phase 1 was divided into 3 experimental series or stages. Stage one included tests only on the coal tar emulsion. Stage 2 was a designed factorial experiment in which the factors were coal tar emulsion, additive and additive source, quantity of additive and quantity of water. Stage 3 was similar to Stage 2 but included sand source, or angularity, gradation and sand quantity.

Phase 2 Laboratory Program- Phase 2 of the laboratory program was designed to expand the phase 1 experiments to include more levels of water and additive. However, sand type and gradation, and some of the test procedures that had low levels of significance in phase 1 were eliminated as variables; and several new tests were added to the experiment.

Additional Laboratory Study- This study was conducted to investigate properties of sand without additives and sand mixtures with a higher sand content than included in the previous experiments.

Final Field Test Installation- Two sets of field test sections were completed near the end of the project. One set included small test pads placed with mixture formulations designed using a procedure developed during the laboratory experimental phases of the study. Suppliers were invited to place additional mixtures at the same time. The second set included larger test pads designed to test the effects of sand quantity on skid test measurements.

The specific materials, material quantities, test procedures, and other factors included in these different parts of the program are presented in the following paragraphs.

PROPERTIES AND TEST METHODS INVESTIGATED

Only a limited amount of information on the testing of coal tar emulsions used as seal coats on asphalt concrete pavements was found during the early phases of this study. Most of the test procedures used by suppliers of coal tar emulsions and latex additives were derived from the paints and coatings industries. The research team began a search for a broader range of test procedures that might be used to define desirable properties of coal tar emulsion seal coats. The procedure involved:

(1) identifying industries with test methods that might relate to seal coat performance
(2) developing or modifying the identified test methods, and
(3) evaluating the potential ability of the selected test procedures to define desirable properties of a coal tar seal coat.

The coal tar, paint, asphalt cement, asphalt concrete, and slurry seal industries were identified as having potentially applicable or adaptable test methods. Tests chosen for evaluation or modification from these industries were:

(1) Brookfield viscosity (9)
(2) Thomas-Stormer viscosity
(3) Scuff resistance, ASTM D 3910 (2), and International Slurry Seal Association, TB139 (21)
(4) Cyclic freeze-thaw conditioning (24)
(5) Flexibility ASTM D 2939 (3)
(6) Wet flow shrinkage, ASTM D 2939
(7) Measuring Adhesion by Tape Test, Method A, ASTM D 3359 (6)
(8) Kerosene resistance, ASTM D 3320 (7), and ASTM D 466
(9) Fuel drip followed by the wet track abrasion (31)

The application of these test procedures to properties of coal tar emulsion formulations is discussed in the following paragraphs.

<u>Workability</u>

The workability of a mixture is characterized by its viscosity. Two devices for measuring viscosity were used in the study.

The Brookfield viscometer was used to measure the apparent viscosity of the coal tar emulsion and the coal tar emulsion with additive, both with and without sand. The viscometer uses a rotating element (spindle) to measure the torque necessary to overcome the resistance to the rotation. The rotational speed and spindle can be chosen to measure a wide range of viscosities.

The Thomas-Stormer viscometer measures the viscosity of a sample using an offset paddle rotor. The load required to produce a rotational speed of 200 rpm is measured, and a value of consistency is determined in Kreb units. Kreb units are a value of a scale commonly used to express the consistency of paints. This device was used with sand mixtures.

Rate of Set and Scuff Resistance

Scuff resistance can be characterized by measuring the time required for the material to cure or set up. Measurement of "cure time" was developed by the slurry seal industry. Cure time is measured by ASTM D 3910 using a cohesion tester. Total curing of the slurry seal is obtained when complete cohesion between the asphalt and aggregate occurs. Along with cure time, the International Slurry Seal Association also measures "set time" and "early rolling traffic time". These limits are obtained by measuring the torque during the development of set and cohesive strength.

Cracking

The cyclic freeze-thaw conditioning was developed from the Lottman accelerated procedure (24) for predicting moisture-induced damage to asphalt concrete pavements. The procedure involves a series of freeze and thaw conditions designed to simulate thermal changes in a pavement in a northern climate.

Flexibility

The flexibility procedure is from the paints and coatings industry, and was intended to measure cracking of a bitumen coating after being exposed to adverse conditions.

The wet flow test is also from the paints and coatings industry. The purpose of the test is to measure the movement of the material when placed in a vertical position.

Adhesion

The test used for adhesion measurements was developed by the paint industry. The test method evaluates the adhesion between a coating and a metallic substrate by applying pressure sensitive tape over cuts made in the coating that has been applied to an aluminum panel and removing the tape.

Fuel Resistance

The resistance to kerosene test is defined by ASTM D 3320, and involves filling a brass ring, which has been glued to an unglazed clay tile coated with the coal tar sealer, with kerosene. The sealer is evaluated for loss of adhesion and kerosene penetration after 24 hours.

The fuel drip and wet track abrasion procedures were developed and modified by the Corps of Engineers, Waterways Experiment Station. The

procedure involves dripping fuel on an asphalt concrete sample, which has been coated with coal tar, and then mechanically abrading the sample. The weight lost during abrasion indicates the ability of the sample to resist damage caused by fuel drippage.

INITIAL FIELD TEST SECTIONS AT THE UNIVERSITY OF NEVADA-RENO

Before starting the laboratory testing program, major coal tar emulsion or additive suppliers were invited to place field test sections on the University campus. The test sections were placed on a low traffic volume parking lot so weathering effects could be monitored without the influence of traffic loads. The parking lot chosen was approximately eight months old and provided a large, uniform surface for the application of the seal coats.

Field samples were collected for laboratory cyclic freeze-thaw analysis by taping asphalt roofing shingles and No. 15 roofing felt to the pavement prior to test section application. Samples were removed after 24 hours of field curing and returned to the laboratory. The procedure for laboratory freeze-thaw analysis is described in the "Test Methods and Procedures" section of this report.

Seventeen field test sections of varying sizes were placed by four suppliers between September 9 and 30, 1986. The mix formulations for the materials placed as test sections are given in Table 3. The layout of the test sections is shown in Figure 1.

The test sections were visually monitored once a month for crack development. The scale used to monitor the cracking included: no cracking, and hairline, slight, moderate, and severe cracking. This was the only testing which was performed at the original field test site.

MATERIALS

Six different coal tar emulsion, additive, and aggregate combinations, supplied by five different commercial sources, were used during various phases of the study. Materials were obtained from Maintenance Inc., Wikel Manufacturing, Engineering Industries, Neyra Industries, and Western Colloid, distributor for a product of Walaschek & Associates. Source numbers were arbitrarily assigned to each supplier, and are identified in Table 4. It was not the purpose of this research program to evaluate product performance but to establish limits on mix variables for laboratory testing and to correlate the limited laboratory testing to field performance. The products were selected to represent the range of materials available, and no endorsement or otherwise of any specific product is intended.

All coal tar emulsions were expected to conform to requirements of Federal Specification RP-355, except that the water content should not exceed 50 percent as required by FAA. Percent solids and specific gravities were determined for the initial supply of coal tar emulsions and are reported in Table 5.

Table 3 University of Nevada Reno Test Sections

Section	Supplier	Prime coat	No of base coats	Top coat w/o sand	Quantity Coal tar (gal)	Quantity Water (gal)	Additive Quantity & type (gal)	Sand loading (lb/gal coal tar)
1	WC	No	2	Yes	100	80	8 2 latex with silicone	13
2	WC	No	1	Yes	100	80	8 2 latex with silicone	13
3	WC	Poly oil & water	2	Yes	100	80	8 2 latex with silicone	--
4	WC	Yes	2	No	80 80	20 20	-- --	4 5
5	WC	No	2	No	------------Asphalt	Emulsion	(20%	cut)------------
6	WC	No	2	No	-----------15%	coal tar,	85% asphalt	emulsion------------
7	MI	No	2&3	No	--	--	Fass Dri	5.4
8	MI	No	2	Yes Top coat	100 100	25 25	25 F S A 10 F S A	10 --
9	MI	Water	2	Yes Top coat	100 100	20 25	10 F S A 10 F S A	5 --
10	MI	J220	2	No	100	20	10 F S A	5
11	MI	No	2	No	100	20	10 F S A	5
12	EI	No	2	Yes†	100	40	4 Tarmax	2
13	EI	No	2	Yes†	100	50	6 Tarmax	6
14	EI	No	2	Yes†	100	40	5 Tarmax	4
15	EI	No	2	Yes†	100	50	7 Tarmax	8
16	NE	Yes	2	No	100	45	15 Armoflex	7
17	NE	Yes	2	No	100	90	10 Tarco plus	6 2

Notes. WC- Western Colloid
MI- Maintenance, Inc
EI- Engineering Industries, Inc
NE- Noyra Industries, Inc

† Top coat on EI sections consisted of : 100 gal coal tar
40 gal water
4 gal Tarmax

Sand used by WC was #20 sand.
Sand used by MI was 2040.
Sand used by EI was silica sand #30.
Sand used by NE was Wedrin 5 30

Sections 1 to 9 were applied with a squeegee.
Sections 12 to 15 were applied with a brush
Sections 16 and 17 were applied with a sprayer.

INITIAL FIELD TEST SECTIONS

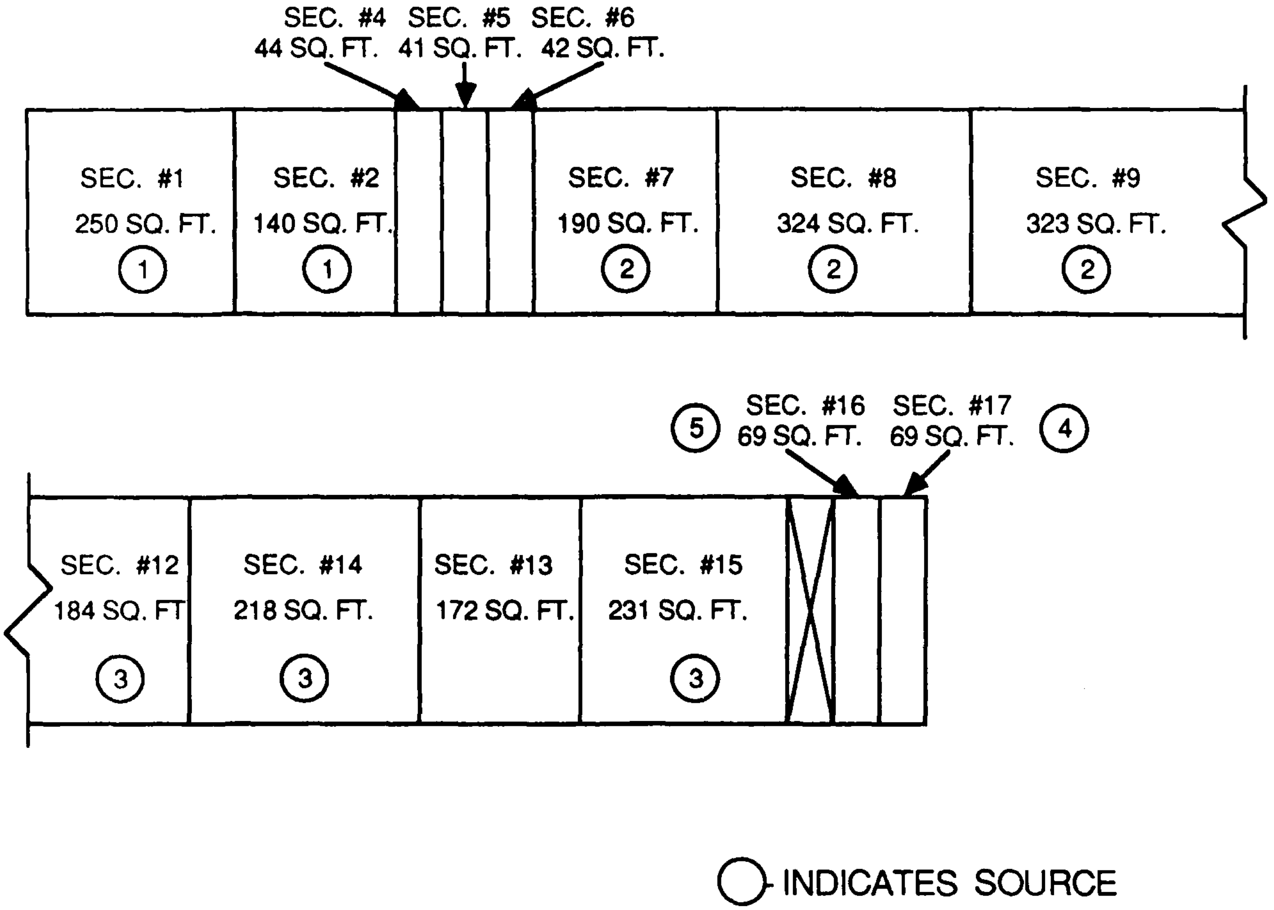


Figure 1 Field Test Section Layout, University of Nevada - Reno

Table 4 - Source Identification

Source Number	Section Nos.	Supplier Code	Additive Name	Additive Code
1	1,2	WC	Walaschek	A-B latex w/ silicone
2	8,9,11	MI	F.S.A.	not A-B latex
3	12,13,14,15	EI	Tarmax	A-B latex w/o silicone
4	17	NE	Tarcoplus	A-B latex w/o silicone
5	16	NE	Armorflex	not A-B latex
6	(1)	WI	Sealex-VM	A-B latex w/silicone

(1) Material received after test pads were placed. Limited tests were performed in the laboratory because of the small supply available.

Table 5 Physical Properties of Materials

Material and Material Property	Source (1)					
	1	2	3	4	5	6
Coal Tar Emulsions						
Solids, % (ASTM D 2939)	58	61	58	50	50	60
Spec. Grav. (ASTM D 2939)	1.23	1.25	1.25	1.22	1.22	1.23
Additives						
Solids, %	41	**	**	**	**	40
Color	blue	green	pink	black	black	green
Spec. Grav.	1.00	1.04	**	**	**	1.00
Silicone, %	3.0	N/A	N/A	**	N/A	3.0
Type	A-B Latex	**	A-B Latex	A-B Latex	Epoxy	A-B Latex
Particle size, Angstroms	500-700	**	**	**	**	1200
Aggregates						
Type	#20	2040	#30	Wedrin 5-30	Wedrin 5-30	N/A
Bulk Spec. Grav.	2.60	2.63	2.58	2.64	2.64	2.63
Bulk Spec. Grav. (SSD)	2.62	2.64	2.62	2.65	2.65	2.64
Absorb. Cap.	0.50	0.15	0.69	0.57	0.57	0.15
Classification	N/A	Angular Fine	Angular Coarse	Round Fine	Round Fine	Round Coarse
Aggregate Gradation - Percent Passing Sieve No.						
#16	100.0	100.0	100.0	100.0	100.0	100.0
#30	93.3	0.0	85.5	0.0	0.0	95.9
#50	4.5	97.6	7.6	72.9	72.9	32.2
#100	0.1	21.1	0.9	13.8	13.9	1.9
#200	0.0	1.1	0.1	0.6	0.6	0.0

** - Information not available N/A - Not applicable

(1) Source 1 - Western Colloid
Source 2 - Maintenance Inc.
Source 3 - Engineering Industries
Source 4 - Neyra Industries
Source 6 - Wikel Manufacturing Co.

The additives consisted of two acrylonitrile-butadiene (AB) latexes with silicone and two without silicone, one epoxy resin, and one proprietary product. The physical properties were supplied by the manufactures and are shown in Table 5.

Five suppliers provided five sand types. A scanning electron microscope (SEM) was used to categorize the shapes of the sand particles according to the particle roundness chart developed by Power's (19). The sand gradation and shapes ranged from fine and rounded to coarse and angular. The physical properties of each aggregate were determined by UNR and are shown in Table 5. The aggregate gradations are given in Table 5.

LABORATORY TESTING

Laboratory testing was conducted in two phases. Phase 1 consisted of preliminary test method evaluation while phase 2 consisted of modifying or refining the test procedures.

Phase 1

Phase 1 consisted of three stages of testing. These stages were the testing of the 1) coal tar emulsion, 2) coal tar emulsion, water, and additive (total liquids), and 3) coal tar emulsion, water, additive, and sand (composite system). The variables included were:

(1) Coal tar source
(2) Additive content
(3) Water content
(4) Sand content
(5) Sand gradation
(6) Sand shape

Stage 1 testing considered the coal tar source as the only variable. Figure 2 shows the tests and the testing sequence for stage 1.

The testing in stages 2 and 3 was performed according to designed experimental plans. The experimental plan used in stage 2 consisted of a three factor, full factorial experiment with three levels for each factor as shown in Table 6. Source, additive quantity, and water quantity were the three factors investigated. The three levels for each factor consisted of low, medium and high quantities. The low and high limits were determined from the range of formulations placed on the field sections by the manufacturers. The medium was selected as the average between the low vand the high limits. Quantities or experimental design levels used in all laboratory experiments are given in Table 7.

Due to the large number of formulations which would result if the testing of stage 3 was conducted from a full factorial design, this experiment was reduced to a partial factorial experiment with two levels for each factor. Sand gradation, sand shape, additive content, water content, and sand content were the variables considered. The two levels

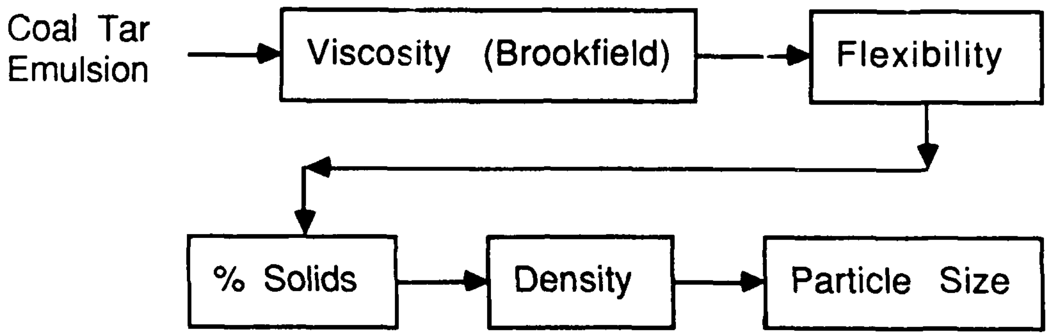


Figure 2: Test Sequence for Stage 1 of Phase 1 Testing

Table 6 Full-Factorial Experiment Design for Phase 1, Stage 2 Testing

	Low Water			Medium Water			High Water		
	Additive			Additive			Additive		
Source	Low	Med.	High	Low	Med.	High	Low	Med.	High
1	X	X	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X	X	X
3	X	X	X	X	X	X	X	X	X
4	X	X	X	X	X	X	X	X	X
5	X	X	X	X	X	X	X	X	X

Table 7 Variable Levels Used in the Laboratory Experiments

Variable	Code	Quantity
	-	0.0 gal/100 gal Coal Tar Emulsion
Additive	L	4.0 gal/100 gal Coal Tar Emulsion
	M	14.5 gal/100 gal Coal Tar Emulsion
	H	25.0 gal/100 gal Coal Tar Emulsion
Water	L	20.0 gal/100 gal Coal Tar Emulsion
	M	55.0 gal/100 gal Coal Tar Emulsion
	H	90.0 gal/100 gal Coal Tar Emulsion
	-	0 lbs/gal Coal Tar Emulsion
Sand Quantity	L	2 lbs/gal Coal Tar Emulsion
	H	13 lbs/gal Coal Tar Emulsion
	-	16 lbs/gal Coal Tar Emulsion
Sand Shape	R	Rounded
	A	Angular
Sand Gradation	F	Fine
	C	Coarse
Sand Combinations Used	RF	Round-Fine
	RC	Round-Coarse
	AF	Angular-Fine
	AC	Angular-Coarse

L = Low
M = Medium
H = High

considered were low and high and were selected as described above. Factors and design levels used in stage 3 are given in Table 8 and 9. The tests and testing sequence included in stages 2 and 3 are shown in Figure 3.

Phase 2

This phase of testing was conducted using a four factor full factorial experiment with three levels for each factor except sand loading, which had two levels. The variables, or factors, which were included in the experiment were coal tar source, additive content, water content, and sand loading. The experiment design for Phase 2 is shown in Table 10. The tests and testing sequence are shown in Figure 4.

TESTS QUANTITIES USED IN LABORATORY EXPERIMENT

The experimental designs included in phase 1 and phase 2 included coded quantities of materials at two or three levels. The levels were chosen to represent the range of quantities included in the formulations applied by suppliers in the initial field test sections. Additional levels were included in final laboratory test series, and in a final field test installation applied at a local airport.

The range of quantities, and applicable code numbers for the designed factorial experiments are given in Table 10.

ADDITIONAL LABORATORY TEST SERIES

At the request of the project sponsor, additional research was performed to study the influence of: 1) no additive, and 2) 16 pounds of sand per gallon of coal tar, on the performance of the coal tar sealers.

The request for the study of the influence of no additive came while conducting the first phase of laboratory testing; so the test sequence followed was the same as that of Phase 1 (Figure 2).

Due to the abundance of source 1 material in the laboratory, it was used to complete this study. The water content was held constant at 55 gal per 100 gal coal tar (medium) for all samples while the sand content was varied as follows:

(1) No sand (0 lbs. per gallon coal tar)
(2) Low sand (2 lbs. per gallon coal tar)
(3) Medium sand (7 lbs. per gallon coal tar)
(4) High sand (13 lbs. per gallon coal tar)

The study of the influence of higher sand loading (16 lbs. per gallon coal tar) was conducted during the completion of Phase 2 laboratory testing. The tests performed are shown in Figure 4 (Test Sequence for Phase 2 Testing), except that the fuel drip and wet track abrasion procedure and the cyclic freeze-thaw conditioning test were not performed. The purpose of the study was to determine the influence of the higher sand loading on the scuff resistance of the mixtures.

Table 8 Two-Factor Factorial Experiment Design for Phase 1, Stage 3 Testing, Sources 1, 2, and 3

			Low Water						High Water					
			Additive						Additive					
			Low			High			Low			High		
	Sand	Sand	Sand			Sand			Sand			Sand		
Source	Type	Grad.	L	M	H	L	M	H	L	M	H	L	M	H
1	R	F	X	X	X	X	X	X	X	X	X	X	X	X
1	R	F	X	X	X	X	X	X	X	X	X	X	X	X
1	R	C	X	X	X	X	X	X	X	X	X	X	X	X
1	R	C	X	X	X	X	X	X	X	X	X	X	X	X
1	A	F	X	X	X	X	X	X	X	X	X	X	X	X
1	A	F	X	X	X	X	X	X	X	X	X	X	X	X
1	A	C	X	X	X	X	X	X	X	X	X	X	X	X
1	A	C	X	X	X	X	X	X	X	X	X	X	X	X
2	R	F	X	X	X	X	X	X	X	X	X	X	X	X
2	R	F	X	X	X	X	X	X	X	X	X	X	X	X
2	R	C	X	X	X	X	X	X	X	X	X	X	X	X
2	R	C	X	X	X	X	X	X	X	X	X	X	X	X
2	A	F	X	X	X	X	X	X	X	X	X	X	X	X
2	A	F	X	X	X	X	X	X	X	X	X	X	X	X
2	A	C	X	X	X	X	X	X	X	X	X	X	X	X
2	A	C	X	X	X	X	X	X	X	X	X	X	X	X
3	R	F	X	X	X	X	X	X	X	X	X	X	X	X
3	R	F	X	X	X	X	X	X	X	X	X	X	X	X
3	R	C	X	X	X	X	X	X	X	X	X	X	X	X
3	R	C	X	X	X	X	X	X	X	X	X	X	X	X
3	A	F	X	X	X	X	X	X	X	X	X	X	X	X
3	A	F	X	X	X	X	X	X	X	X	X	X	X	X
3	A	C	X	X	X	X	X	X	X	X	X	X	X	X
3	A	C	X	X	X	X	X	X	X	X	X	X	X	X

L = Low
M = Medium
H = High

F = Fine
C = Coarse

R = Round
A = Angular

Table 9 Two-Factor Factorial Experiment Design for Phase 1, Stage 3 Testing, Sources 4 and 5

			Low Water						High Water					
			Additive						Additive					
			Low			High			Low			High		
	Sand	Sand	Sand			Sand			Sand			Sand		
Source	Type	Grad.	L	M	H	L	M	H	L	M	H	L	M	H
4	R	F	X	X	X	X	X	X	X	X	X	X	X	X
4	R	F	X	X	X	X	X	X	X	X	X	X	X	X
4	R	C	X	X	X	X	X	X	X	X	X	X	X	X
4	R	C	X	X	X	X	X	X	X	X	X	X	X	X
4	A	F	X	X	X	X	X	X	X	X	X	X	X	X
4	A	F	X	X	X	X	X	X	X	X	X	X	X	X
4	A	C	X	X	X	X	X	X	X	X	X	X	X	X
4	A	C	X	X	X	X	X	X	X	X	X	X	X	X
5	R	F	X	X	X	X	X	X	X	X	X	X	X	X
5	R	F	X	X	X	X	X	X	X	X	X	X	X	X
5	R	C	X	X	X	X	X	X	X	X	X	X	X	X
5	R	C	X	X	X	X	X	X	X	X	X	X	X	X
5	A	F	X	X	X	X	X	X	X	X	X	X	X	X
5	A	F	X	X	X	X	X	X	X	X	X	X	X	X
5	A	C	X	X	X	X	X	X	X	X	X	X	X	X
5	A	C	X	X	X	X	X	X	X	X	X	X	X	X

L = Low　F = Fine　R = Round
M = Medium　C = Coarse　A = Angular
H = High

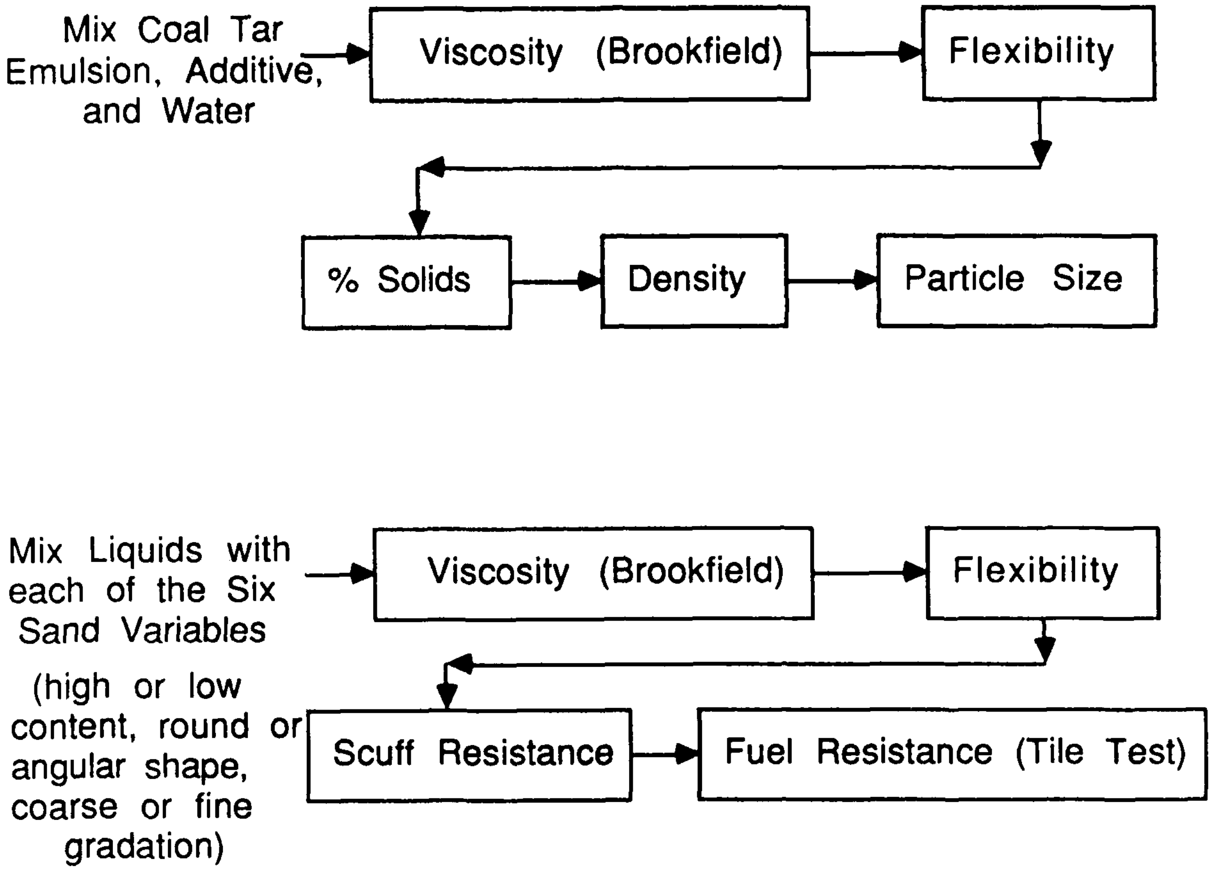


Figure 3: Test Sequence for Stages 2 and 3 of Phase 1 Testing

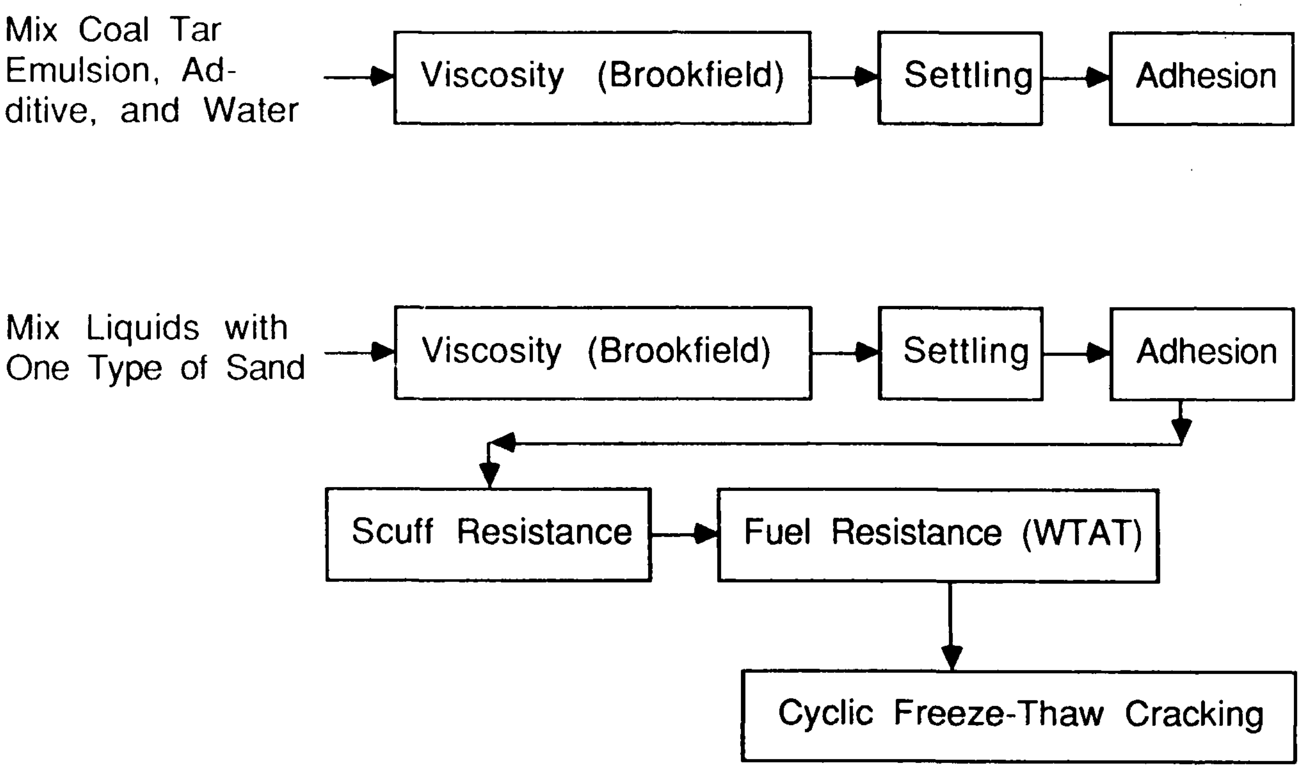


Figure 4: Test Sequence for Stage 2 Testing

Table 10 Full-Factorial Design for Phase 2 Testing

		Additive								
		Low			Medium			High		
		Water			Water			Water		
Source	Sand	L	M	H	L	M	H	L	M	H
1	L	X	X	X	X*	X	X*	X	X	X
1	H	X	X	X	X*	X	X*	X	X	X
2	L	X	X	X	X*	X	X*	X	X	X
2	H	X	X	X	X*	X	X*	X	X	X
3	L	X	X	X	X*	X	X*	X	X	X
3	H	X	X	X	X*	X	X*	X	X	X
4	L	X	X	X	X*	X	X*	X	X	X
4	H	X	X	X	X*	X	X*	X	X	X
6	L	X	X	X	X*	X	X*	X	X	X
6	H	X	X	X	X*	X	X*	X	X	X

* Mixture used for wet track abrasion procedure

The mixtures tested consisted of three samples from the original full-factorial design for Phase 2 and three additional samples at 16 lbs. of sand per gallon of coal tar emulsion. The original samples had additive and sand contents of 14.5 gallon per 100 gallon coal tar (medium) and 13 lbs. per gallon coal tar (high) respectively. The three additional samples tested had additive and sand contents of 14.5 gallon per 100 gallon coal tar and 16 lbs. per gallon coal tar respectively. Within each set of three samples, the water content varied as follows:

(1) Low (20 gal per 100 gal coal tar)
(2) Medium (55 gal per 100 gal coal tar)
(3) High (90 gal per 100 gal coal tar)

FINAL FIELD TEST SECTIONS AT STEAD AIRPORT

Three sets of field sections were placed at the conclusion of the laboratory study at Stead General Aviation Airport, located near Reno. The first set included small test pads, placed with formulations recommended by the University research staff. A mix design procedure developed in the laboratory study, phase 2, was used to select quantities. The second set included small test pads using materials and quantities selected by the suppliers. The third set included larger sections designed to provide means for skid testing coal tar emulsion formulations with variable levels of sand loading. All of these sections included 10 gal of additive from supplier No. 1, Table 4, plus 5, 8 and 16 lb sand loadings. Wet and dry skid tests were performed on these sections, using the FAA SAAB runway friction tester, approximately three months after placement.

LABORATORY TEST METHODS AND PROCEDURES

The laboratory investigation, conducted at the University of Nevada Reno as part of this study, has as its major objective the development of tests that would measure or reflect performance-related properties of coal tar emulsion seal coats. It was expected that the results of the laboratory study could be used to develop mix design procedures, and establish specification and quality assurance criteria.

Properties considered significant in this study included:

(1) Workability
(2) Rate of Set and Resistance to Scuffing
(3) Cracking
(4) Adhesion
(5) Fuel Resistance

TEST PROCEDURES

Only a limited amount of information on the testing of coal tar emulsions used as seal coats on asphalt concrete pavements was found during the early phases of this study. The coal tar, paint, asphalt cement, asphalt concrete, and slurry seal industries were identified as having potentially applicable or adaptable test methods. Tests chosen for

evaluation or modification from these industries were described briefly in the preceding paragraphs and are discussed below under the property that they were selected to measure.

The discussion includes the following properties and test procedures:

(1) Workability
  (a) Brookfield viscosity
  (b) Thomas-Stormer viscosity (settling test)

(2) Rate of Set and Resistance to Scuffing
  (a) Scuff resistance

(3) Cracking
  (a) Cyclic freeze-thaw conditioning
  (b) Flexibility
  (c) Wet flow shrinkage

(4) Adhesion
  (a) Measuring adhesion by tape test

(5) Fuel Resistance
  (a) Kerosene resistance (Tile Test)
  (b) Fuel drip followed by the wet track abrasion

The procedures followed in experimentation with these test procedures are described in the following paragraphs. Mixtures containing coal tar emulsion, additive, and added water are referred to as the total liquids. Total liquids and sand mixture are referred to as the composite system.

WORKABILITY TEST

Workability of a coal tar mixture is important because it governs the method of application. If the mix is too stiff, it will be difficult to squeegee, and if the mix is too thin, it will be difficult to keep the sand in suspension while spraying. For this research project the workability was monitored through viscosity and settling measurements. The procedures for these tests are given below.

Viscosity

Both the Thomas - Stormer viscometer, Figure 5, and Brookfield viscometer, Figure 6, were considered for determining viscosity of coal tar emulsion mixtures.

The Thomas-Stormer viscometer was recommended by the coal tar industry to measure the viscosity of the mixtures because of its ability to measure the viscosity of a thixotropic material. The Thomas-Stormer uses weights to drive a paddle, at 200 revolutions per minute, to measure the viscosity of a material. After a preliminary study it was found that the Thomas-Stormer would be unacceptable for viscosity measurements of shear thinning material. This is because weights need to be added or

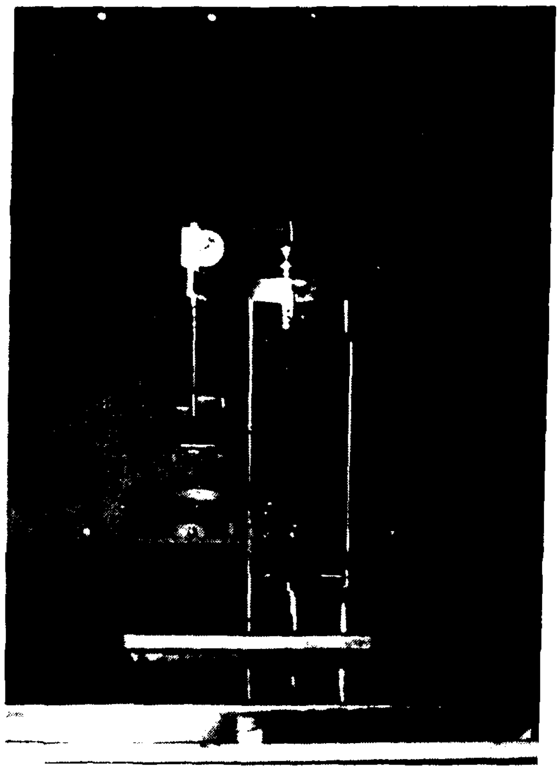


Figure 5: Thomas-Stormer Viscometer

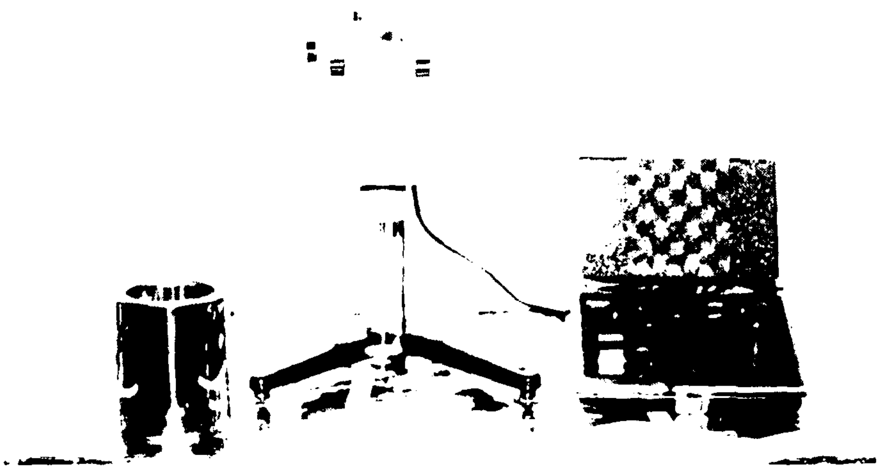


Figure 6: Brookfield Viscometer

subtracted to adjust the speed of the paddle to 200 revolutions per minute. If that rotational speed is not achieved on the first try, then the sample must be disposed of and a new sample used.

The Brookfield Viscometer DV II was chosen finally for routine viscosity measurements, because of its ease of operation and its wide range of viscosity measuring capabilities. The Brookfield viscometer rotates a spindle through a beryllium copper spring; the degree to which the spring is wound is proportional to the viscosity of the material. Due to the shear thinning characteristic of coal tar emulsions, the testing procedure was controlled as follows.

The coal tar emulsion and water were mixed with 50 strokes of a large laboratory mixing spoon. A Brookfield spindle was then inserted into the material and allowed to rotate for 5 seconds before a viscosity measurement was taken. The additive was then introduced into the mixture, and stirred an additional 50 strokes of the mixing spoon. The viscosity was measured as before. Sand was then added to the mixture, stirred with 50 strokes and the final viscosity measured.

The temperature susceptibility of the mixture was also examined. This was accomplished by bringing each component to temperature (34,77, or 104°F) 48 hours prior to testing. Samples were mixed and viscosity measurements taken using the same procedure described above. Temperature susceptibility of the mixtures was not examined during the Phase 2 study.

Settling

The Thomas-Stormer Viscometer was used to monitor the ability of the mixture to support sand. The method was derived from a procedure used to determine the yield point of an asphalt emulsion. The settling test was not performed in Phase 1 of the research program.

The following procedure was used for the settling test.

The coal tar emulsion, water and additive were mixed in the same manner as for the viscosity sample. After mixing, one pint of the material was placed in a pint paint container. The Stormer paddle was inserted in the sample, approximately one inch from the bottom of the can. The brake was released on the viscometer, and the weight and time required to rotate the paddle five revolutions was recorded. The sample was then place on the shelf.

Sand was added to the remaining material and a pint can was filled with the mixture. The settling measurement was then taken in the same manner as before. The procedure was repeated for both samples (total liquids and composite system) after 24 hours of uninterrupted sitting.

The settling value (SV) for each sample was calculated as follows:

SV = (T*W)/R

where

T = time required for paddle to rotate five revolutions (seconds)
W = weight required to rotate paddle five revolutions (grams)
R = number of revolutions (in this case five)

The settling ratio (SR) is then computed as:

SR = SV (final)/SV (initial)

RATE OF SET AND RESISTANCE TO SCUFFING

"Scuff" test procedures and equipment were developed to measure both the rate of set and the final scuff resistance of the coal tar sealers. It is thought that this information might prove useful in determining when a pavement, which has been sealed, could be opened to traffic or if the sealer provides adequate scuff resistance.

The test procedures and equipment were developed with the aid of the International Slurry Seal Association (ISSA) Technical Bulletin (TB) 139, " Test Method to Classify Emulsified Asphalt/Aggregate Mixture Systems by Modified Cohesion Tester Measurements of Set and Cure Characteristics" (21), and the American Society for Testing and Materials D 3910-84, "Design, Testing, and Construction of Slurry Seal" (2).

During the development of the equipment, several factors were considered important, namely portability and ease of use. It was also considered desirable to use asphalt roofing shingles as the test medium because of their durability and coarse surface texture. In the development of the test procedures, information from the ISSA TB 139 was used to determine a general torque versus time relationship for each mix. After reviewing the ISSA's recommendations, a torque wrench with a capacity of 150 in-lbs was chosen. Details from ASTM D 3910 were used to determine the 28 psi pressure to be applied to the sample.

Scuff Test Procedure

In this procedure, the coal tar emulsion sealer mixtures were applied to five 6-inch by 6-inch sections of asphalt roofing shingle. A uniform film thickness of coal tar emulsion was applied to each shingle using a 16-gauge sheet metal mask. The mask was 6-inch by 6-inch with a 4-inch by 4-inch section removed from the center (Figure 7). A straight edge was used to apply the material in the mask. Only one thickness of material was applied, and the samples were allowed to cure at ambient temperature (77°F) and 13 to 20 percent relative humidity. A shingle was placed on the platen of the testing machine and held in place with "C" clamps. The platen was then raised upward to the rubber abrasion head, and a normal load of 28 psi was applied to the sample through a calibrated proving ring (Figure 8). The torque wrench was then pulled through an arc of 180 degrees and a torque reading was taken in inch-pounds. This reading

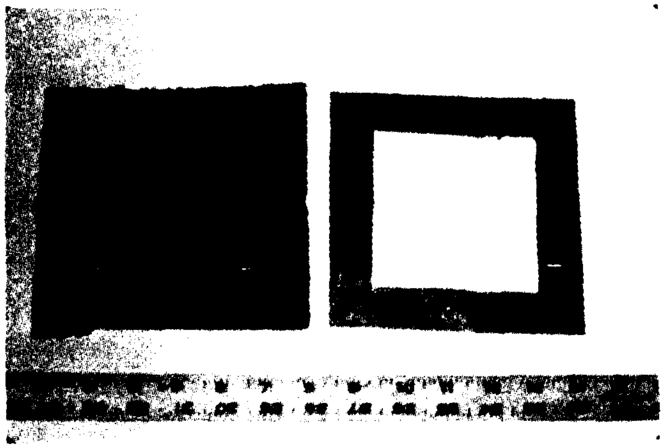


Figure 7: Shingle and Mask Used for Scuff Test Samples

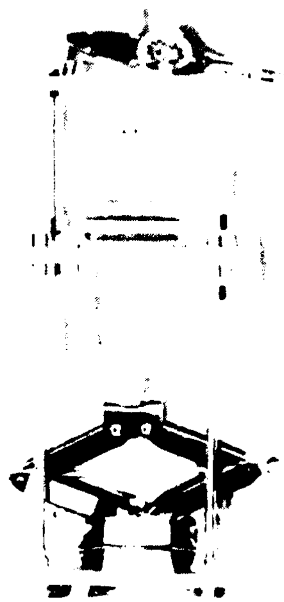


Figure 8: Scuff Test Apparatus

indicates the resistance of the rubber hose on the sample. Separate samples were tested once every hour for four hours and the fifth sample was tested at 24 hours.

A majority of the samples tested at 24 hours exceeded the maximum range of the torque wrench. For this reason, a torque wrench with a capacity of 300 in-lbs was used in Phase 2.

The testing procedure in Phase 2 was the same as that described above except that six shingles were prepared in order to test samples one every hour for four hours, one at eight hours, and one at 24 hours. As mentioned before, a torque wrench with a capacity of 300 in-lbs was used in this phase.

CRACKING

Cracking of a coal tar sealer can provide a path for petroleum products or water to penetrate and deteriorate the underlying asphalt concrete pavement. The cracking can be caused by volume changes resulting from temperature changes, shrinkage or brittleness of the coating. The tests chosen to monitor cracking included: 1) cyclic freeze-thaw conditioning, 2) flexibility, and 3) shrinkage testing. These three tests are described below.

Cyclic Freeze-Thaw

The sequence of temperature and times used in this test were selected from the Lottman procedure for predicting asphalt pavement damage. The differences between the Lottman procedure and the method used in the research program were: 1) a dry $140^{\circ}F$ conditioning was substituted for a wet $140^{\circ}F$ conditioning, and 2) the $140^{\circ}F$ temperature was used to complete the curing of the samples.

During the preliminary test development stage, separate samples from the different field test sections were exposed to three methods of sample conditioning: 1) freeze-thaw cycles, 2) $140^{\circ}F$, and 3) $10^{\circ}F$. After a relatively short period of testing it became apparent that the freeze-thaw conditioning would reveal the most information about crack development and the other two methods were discontinued. The freeze-thaw conditioning procedure was as follows.

A coal tar emulsion mixture was applied to a 6-inch by 6-inch section of asphalt roofing shingle. One layer of sealer was applied to form a uniform film thickness. This was accomplished by using a 16-gauge sheet metal mask. The mask was 6-inch by 6-inch with a 4-inch by 4-inch section removed from the center.

After application, the sample was allowed to cure at $77^{\circ}F$ and 13 to 20 percent relative humidity for 24 hours. After the initial curing, samples were placed in a $140^{\circ}F$ oven for 24 hours, then moved to a $10^{\circ}F$ freezer for 24 hours. This procedure constituted 1 freeze-thaw cycle; samples were subjected to a total of 10 cycles. Samples were monitored for

cracking after each cycle using the cracking scale developed for the field test sections. During this phase of the testing it was found that the sample size of 6-inch by 6-inch was too small to develop cracking. This is because the thermal stress and shrinkage is related to the surface area of the sample.

The procedure followed in phase 2 was the same as that of Phase 1 except the material was applied to a 12-inch by 12-inch instead of a 6-inch by 6-inch section of asphalt roofing shingle.

Performance in the cyclic freeze-thaw test was measured using the following scale:

0 - No cracking
1 - Hairline cracking
2 - Slight cracking
3 - Moderate cracking
4 - Severe cracking

Examples of specimens rated 1,2,3 and 4 are shown in Figure 9.

Flexibility

The flexibility test was performed according to ASTM D 2939 (3), "Emulsified Bitumens used as Protective Coatings". The only exception was that an aluminum panel was used as the sample medium instead of a silicon-coated, aluminum-laminate, release-paper panel. The reason for the change was the inability to locate the sample medium called for in the ASTM standard. The procedure for the flexibility test is described as follows. The mask is shown in Figure 10.

The coal tar mixture was applied in the same manner as the freeze-thaw sample except a 3-inch by 6-inch mask is used and three samples were prepared. After application, the sample was allowed to cure for 24 hours at 77°F and 13 to 20 percent relative humidity. The sample was then placed, in a vertical position, in the 140°F oven for 5 hours. After curing in the oven the sample was cooled to room temperature then immersed in a 32°F water bath for 1 hour. The sample was removed from the water bath and then bent around a mandrel which had also been chilled to 32°F. Cracking was then measured.

A subjective rating scale was developed from observed cracking patterns. This rating scale is as follows:

0 - No visible metal beneath cracks, hairline cracks were noted
1 - One to two cracks
2 - Three to four cracks
3 - Five to six cracks
4 - Seven to eight cracks
5 - Nine to ten cracks

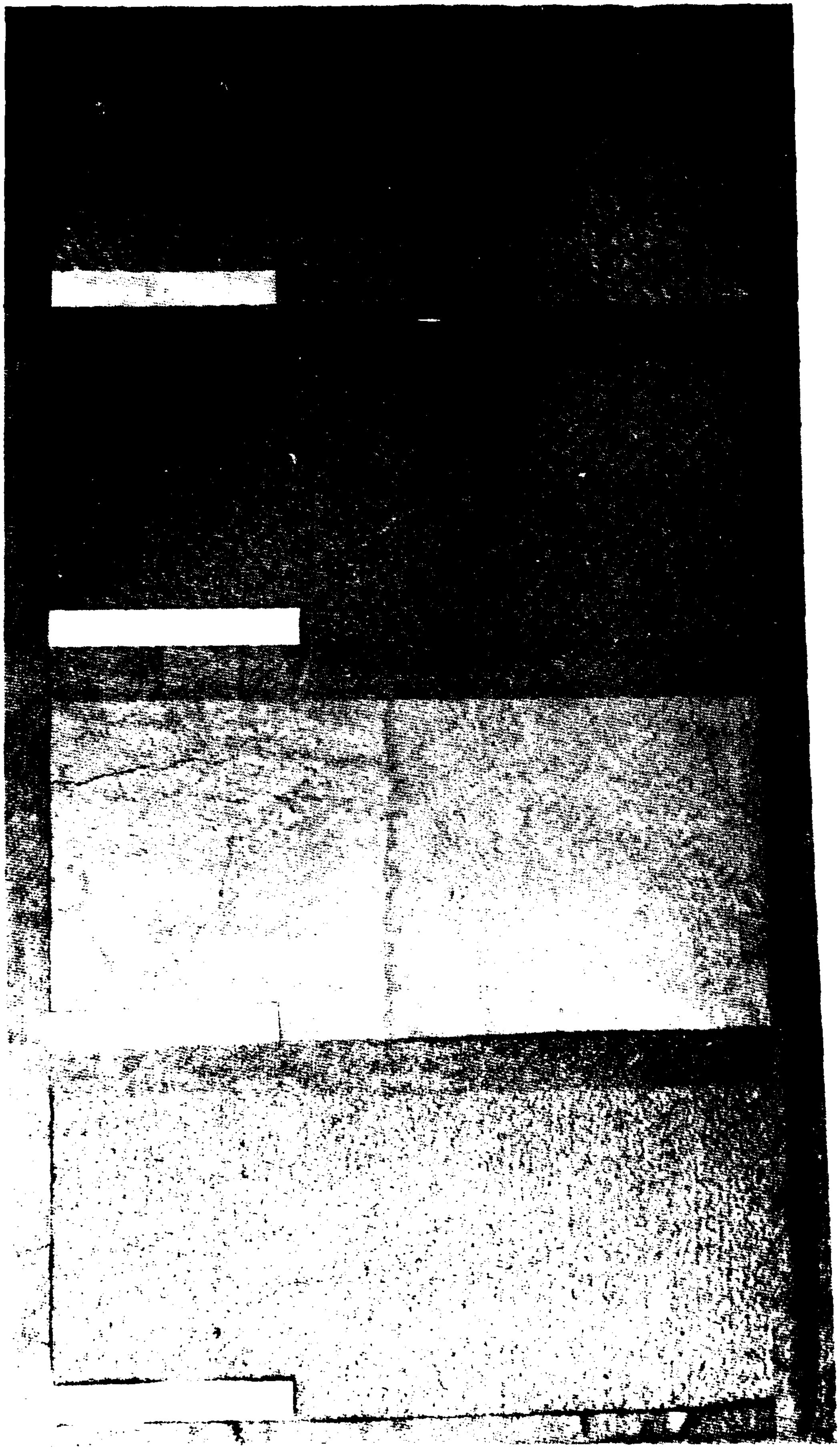


Figure 9: Crack Rating System Developed for Cyclic Freeze-Thaw Conditioning

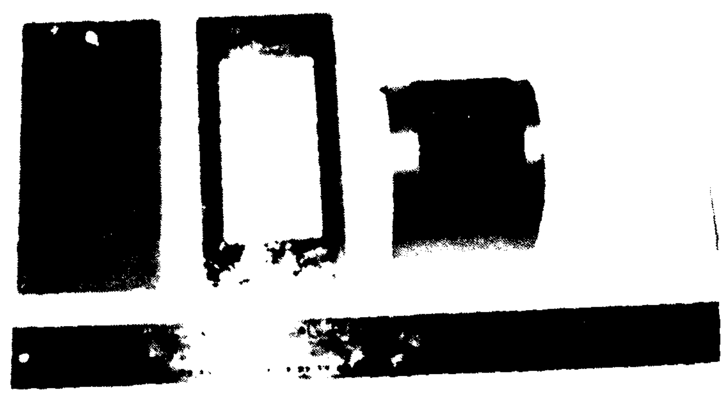


Figure 10: Aluminum Panel and Mask Used for Flexibility, Shrinkage, and Adhesion Samples

Cracks were defined as being greater than or equal to one half the width (2 inches) of the sample.

After evaluation of the results compiled in Phase 1, the flexibility test was eliminated from consideration in Phase 2 because the test was not sensitive to mix component changes.

Shrinkage

The idea for the shrinkage test came from ASTM D 2939, "Emulsified Bitumens used as Protective Coatings." Section 13, titled "wet flow". The purpose of the wet flow test is to measure flow of an emulsion which is held in a vertical position. The procedure developed for the research program is as follows.

The sample was prepared in the same manner as that in the flexibility test. While the mix was still wet, a reference line was scribed on the panel, coincident with one edge of the coating. One panel each was kept at -20°, 77°, and 140°F for 24 hours. After 24 hours, the movement of the coating with respect to the reference line was measured with a micrometer.

The properties of the mixtures (too thick or too thin) was such that an accurate measurement of the coating movement could not be taken so a scale was not developed.

Due to the difficulties encountered in Phase 1, the shrinkage test was not performed in Phase 2 of the research program.

ADHESION

With the peeling and debonding problems common in the field, a test to predict the loss of adhesion between the coal tar sealer and the pavement was deemed necessary. Loss of adhesion between the sealer and the pavement can lead to poor fuel and water resistance, which can lead to deterioration of the pavement. The test chosen to measure adhesion comes from ASTM D 3359, "Measuring Adhesion by Tape Test". Method A, "X-cut tape test", of this procedure was used because the final film thickness of the sealer exceeded 5 mils (125¯6m). The test method used is as follows.

A coal tar emulsion mixture was applied to a 3-inch by 6-inch aluminum panel in the same fashion as for the flexibility sample. The sample was allowed to cure for 24 hours at approximately 77°F and 13 to 20 percent relative humidity. After the curing was complete, an "X" was cut in the sealer so the panel was visible. A length of pressure sensitive tape (40 oz/in of width) was then applied so the centers of the "X's were covered with the tape. The tape was then peeled back and the adhesion between the sealer and the panel was measured.

The scale used to measure adhesion was defined by ASTM D 3359 and is as follows:

5A - No peeling or removal
4A - Trace peeling or removal along incisions
3A - Jagged removal along most of incision up to 1/16 in. on either side
2A - Jagged removal along most of incision up to 1/8 in. on either side
1A - Removal from most of the area of the X under tape
0A - Removal beyond the area of the X

The "A" designation after the numerical rating designates that method A was used in the testing. An adhesion test was not performed in Phase 1 of the research program.

FUEL RESISTANCE

A significant amount of damage occurs to asphalt concrete pavement each year due to spillage of fuel, oil, and hydraulic fluids. One method of reducing the damage is to seal the pavement with a coal tar emulsion seal coat.

The purpose of this testing was to evaluate how the sealer performed as a result of being exposed to petroleum products. The tests used in the evaluation included the Resistance to Kerosene, or Tile test, ASTM D 3320, and the Fuel Drip followed by the Wet Track Abrasion test (32). The test procedures are described below.

Tile Test

Resistance to Kerosene or the Tile test was used to evaluate the fuel resistance in Phase 1 of the testing program. The test method comes directly from ASTM D 3320 "Emulsified Coal Tar Pitch (Mineral Colloid Type)"(7), using a procedure described in ASTM D 466. The procedure is described below.

A coal tar emulsion mixture was applied to a 6-inch by 6-inch white, unglazed ceramic tile. A uniform thickness was applied using a 16-gauge sheet metal mask. The mask was 6-inch by 6-inch with a 4-inch by 4-inch section removed from the center. Only one thickness of material was applied. The sample was then allowed to cure for 96 hours at approximately 77°F and 13 to 20 percent relative humidity. After the curing stage, a brass ring (2 inches in diameter and 2 inches high) was affixed to the sealer with silicon rubber. The brass ring was then filled with kerosene. After 24 hours, the coating was evaluated for loss of adhesion and penetration of the jet fuel into the sealer.

The Tile test was not performed in Phase 2 of the research program because the test was not sensitive to mixture component changes.

Fuel Drip Followed By The Wet Track Abrasion Procedure

The fuel drip followed by the wet track abrasion procedure was used to evaluate the fuel resistance of a coal tar sealer in the second phase of the research program. The test procedure used was that developed by the Corps of Engineers at the Waterways Experiment Station (13) as given below.

Asphalt concrete briquets were completely sealed with a coal tar emulsion mixture. The cylindrical samples were 6 inches in diameter and approximately 2 inches high. A total of 3 samples were sealed for each mixture tested. The height and weight were taken before and after sealing in order to calculate the approximate application rate. The coal tar emulsion was applied using a 1.5-inch nylon paint brush. The samples were allowed to cure for 24 hours at 77°F and 13 to 20 percent relative humidity.

At the end the curing cycle, the samples were exposed to the fuel drip test. Jet fuel (Jet A) was dripped on the sample for 5 minutes under a constant pressure of 5 psi. The sample was rotated every 2.5 minutes to insure complete coverage of the briquet by the jet fuel. Immediately following the fuel drip procedure, the sample was placed in the wet track abrasion apparatus. The metal pan was filled with enough water to completely cover the sample. This was done to reduce the heat caused by friction between the sample and the abrasion head. The sample was then abraded for a total of 10 minutes.

After the wet track abrasion procedure the sample was washed off to remove the abraded debris. Care was taken to avoid dislodging of the larger aggregate. The sample was then allowed to dry at room temperature for 24 hours. The difference between the initial and final weights was used as an indication of loss of adhesion or fuel penetration. The fuel drip followed by the wet track abrasion procedure was not performed during Phase 1 of the research program.

The apparatus used in this test is shown in Figures 11 and 12.

TEST RESULTS

Results of test performed in the experiments described in this chapter are presented and evaluated in the next chapter.

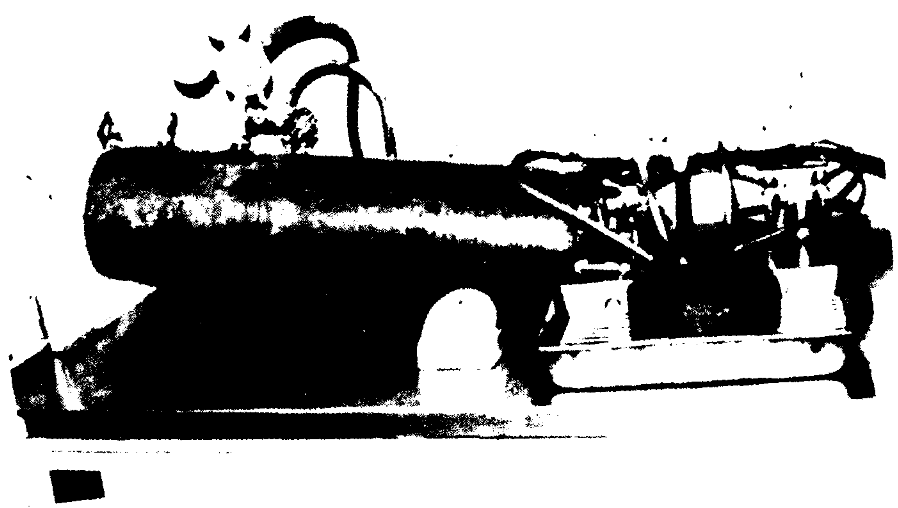


Figure 11: Fuel Drip Apparatus

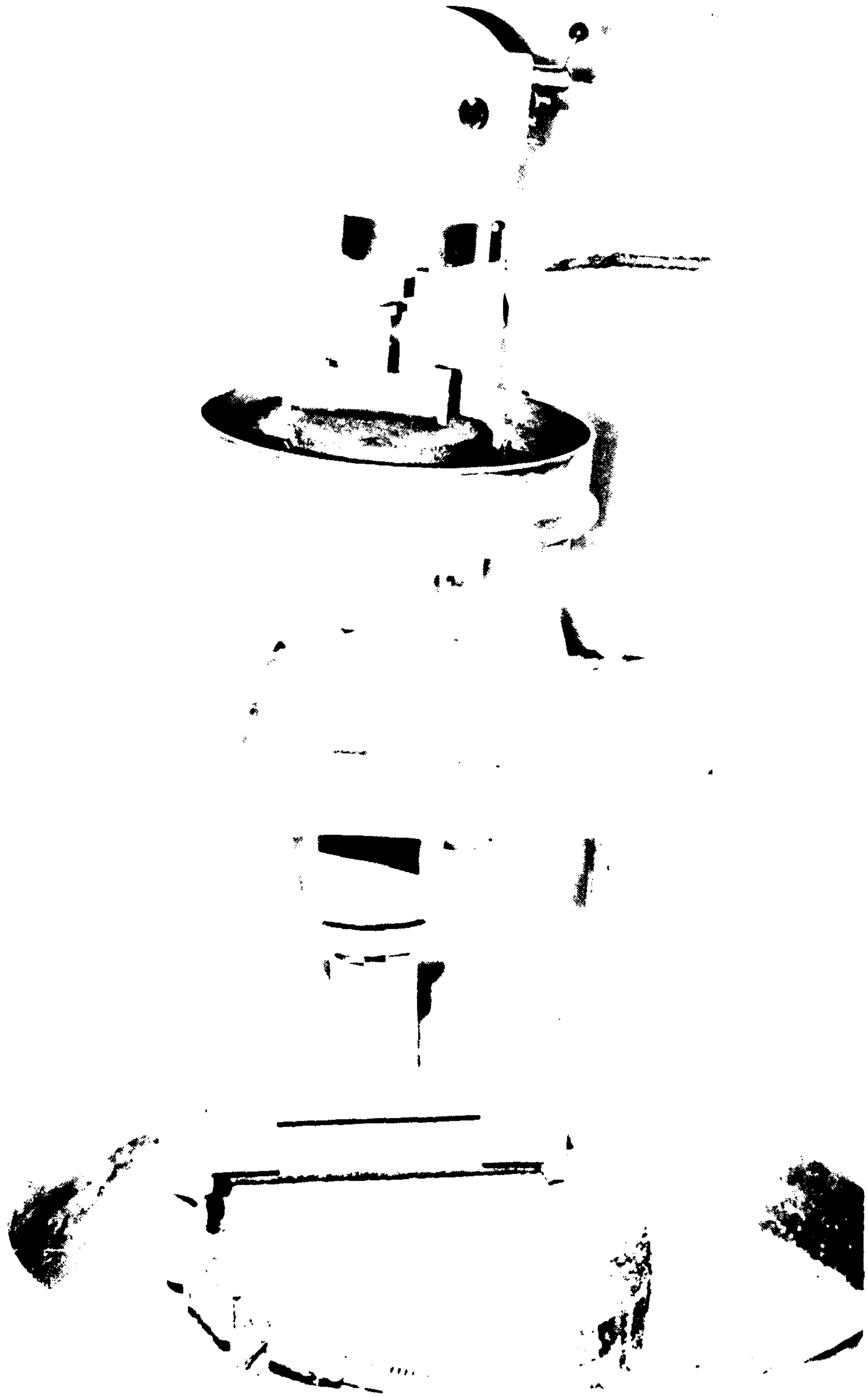


Figure 12: Wet Track Abrasion Apparatus

CHAPTER III LABORATORY TEST RESULTS

INTRODUCTION

The laboratory investigation conducted at the University of Nevada at Reno, as part of this study, had as its major objective the development of tests that would measure or reflect performance-related properties of coal tar emulsion seal coats. It was expected that the results of the laboratory study could be used to develop mix design procedures, and establish specification and quality control criteria.

Properties considered significant in this study included:

(1) Workability
(2) Rate of Set and Resistance to Scuffing
(3) Cracking
(4) Adhesion
(5) Fuel Resistance

The test procedures used to measure these properties were presented in Chapter II. The purpose of this chapter is to indicate how changes in mix formulations, ie, proportions of coal tar emulsion, additive, water, and sand, affected the properties listed above. How this information might be used to select mix proportions and establish mix design and quality control criteria is discussed in later chapters.

The presentation follows the previously established order of presentation, in that each test is discussed under the heading of the material property to which it applies. However, the laboratory program included several series of tests, each with a different experiment design, as well as related field study constructed at the beginning of the project. Since each series of tests was different in many respects, and had some influence on the subsequent test series, a separate presentation of data is included for each series under each test heading.

Information on the separate phases of the laboratory program were presented in Chapter II, and are repeated here for reference.

Materials Used- Materials used in the experiment are described in Tables 4 and 5, results of additional tests on the coal tar emulsion only are given in Table 11.

Initial Field Test Installations- Initial field test installations provided an opportunity for suppliers of coal tar emulsion sealers to place their recommended formulations, and, for the University research staff to develop a first-hand knowledge of the materials. In addition, materials and material quantities placed in the field were used as the basis for selecting materials and quantities to be included in laboratory testing program. The materials and formulations used in this part of the study is described in Table 3; the experimental layout in Figure 1.

Table 11 Test Results For Phase 1, Stage 1 Testing (Coal Tar Emulsion only)

	Source					
Test	1	2	3	4	5	6
Flexibility	1	0	2	0	0	1
(3 tests	0	1	1	1	1	1
per Source)*	1	0	2	1	1	2
(ASTM 2939)						
Density, lb/gal (ASTM 2939)	10.24	10.43	10.43	10.35	10.35	10.23
Residue by Evaporation (ASTM 2939)						
Dried to Constant Weight (3 Hours), %	58.4	60.9	58.4	49.9	49.9	59.7
Dried 24 hours, %	57.6	58.8	55.3	47.8	47.8	58.7
Viscosity						
34 F, Poise	103	59	159	80	80	139
77 F, Poise	104	56	141	76	76	153
104 F, Poise	104	57	135	69	69	122

* - Flexibility Rating
- 0 = No Visible Metal
- 1 = 1-2 cracks
- 2 = 3-4 cracks
- 3 = 5-6 cracks
- 4 = 7-8 cracks
- 5 = 9-10 cracks

Phase 1 Laboratory Program- Phase 1 of the laboratory test program was designed to determine material properties and to evaluate potential test procedures. The program also was used to screen out those test variables that had only a small influence on seal coat properties. Phase 1 was divided into 3 experimental stages. Stage one included test performed only on the coal tar emulsion. Stage 2 was a designed factorial experiment in which the factors were coal tar emulsion and additive from each source, quantity of additive, and quantity of water. Stage 3 was similar to Stage 2 but included sand source, angularity, gradation and quantity. The experiment design for this phase of the experiment is shown in Tables 6,7 and 8; the testing sequence in Figure 2 and 3.

Phase 2 Laboratory Program- Phase 2 of the laboratory program was designed to expand the phase 1 experiment to include more levels of water and additive. However, sand type and gradation, and some of the test procedures that had low levels of significance in phase 1, were eliminated as variables; and several new tests were were added to the experiment. The experiment design for phase 2 is shown in Table 9; the testing sequence in Figure 4.

Additional Laboratory Study- This study was conducted to investigate properties of sand without additives and sand mixtures with a higher sand content than included in the previous experiments.

Final Field Test Installation- Two sets of field test sections were completed near the end of the project. One set included small test pads placed with mixture formulations designed using a procedure developed during the laboratory experimental phases of the study. Suppliers were invited to place additional mixtures at the same time. The second set included larger test pads designed to test the effects of sand quantity on skid test measurements. Because this phase of the program was conducted at the end of the project, only a limited amount of data is available. The materials and other details of this portion of the experiment are given in Chapter IV.

Data obtained in the laboratory program are included in Appendixes C through G.

The influence of mix variables on coal tar emulsion mix properties are shown in the following paragraphs. The test results are presented and discussed under the following headings, corresponding to the properties determined earlier to be significant:

(1) Workability
(2) Rate of Set and Resistance to Scuffing
(3) Cracking
(4) Fuel Resistance

WORKABILITY

Workability test data are given in Appendix C.

Results of analyses of the test data are given in the following paragraphs.

Viscosity

As previously mentioned, Phase 1 of the testing consisted of three testing stages. These stages included determining the Brookfield viscosity of the following combinations:

(1) Coal tar emulsion (base)
(2) Coal tar emulsion, additive, and water (total liquids)
(3) Coal tar emulsion, additive, water, and sand (composite system)

Phase 1 - Viscosity of Base Material. Table 11 presents the results of the testing in stage 1, Phase 1. As shown in Figure 13, Stage 1 also included an evaluation of the temperature susceptibility of the coal tar emulsion. Figure 13 shows that the coal tar in an emulsion form is not very susceptible to temperature differences.

Phase 1 - Viscosity of Total Liquids. Stage 2 of the testing was performed according to a three factor, full factorial experiment with 3 levels for each factor.

The following paragraphs will consider the effects of additive and water content on viscosity readings.

Additive: Table 12 shows the influence of three different levels of additive content and six different sources on viscosity readings. The data indicated that the effect of additive content varies with source, and no definite trends are indicated.

Water: Relationships were developed for three water contents: 20, 55, and 90 gal/100 gal coal tar emulsion. Figure 14 shows viscosity versus water content for sources 1, 3, and 4, in which the additive used is an acrylonitrile-butadiene (AB) latex. Figure 15 shows viscosity versus water content for sources 2 and 5 in which the additive used is a proprietary product and an epoxy resin respectively. Two observations can be made from these figures: (1) viscosity is extremely source dependent and (2) viscosity decreases with increase in water content.

Table 13 presents a summary of the influence of increasing water content on viscosity readings. It is clear that the viscosity decreases with increased water content regardless of the additive content.

Phase 1 - Viscosity of Composite System. Because this stage was performed according to a partial factorial experiment design, only limited trends can be developed with any certainty. The only trend which will be

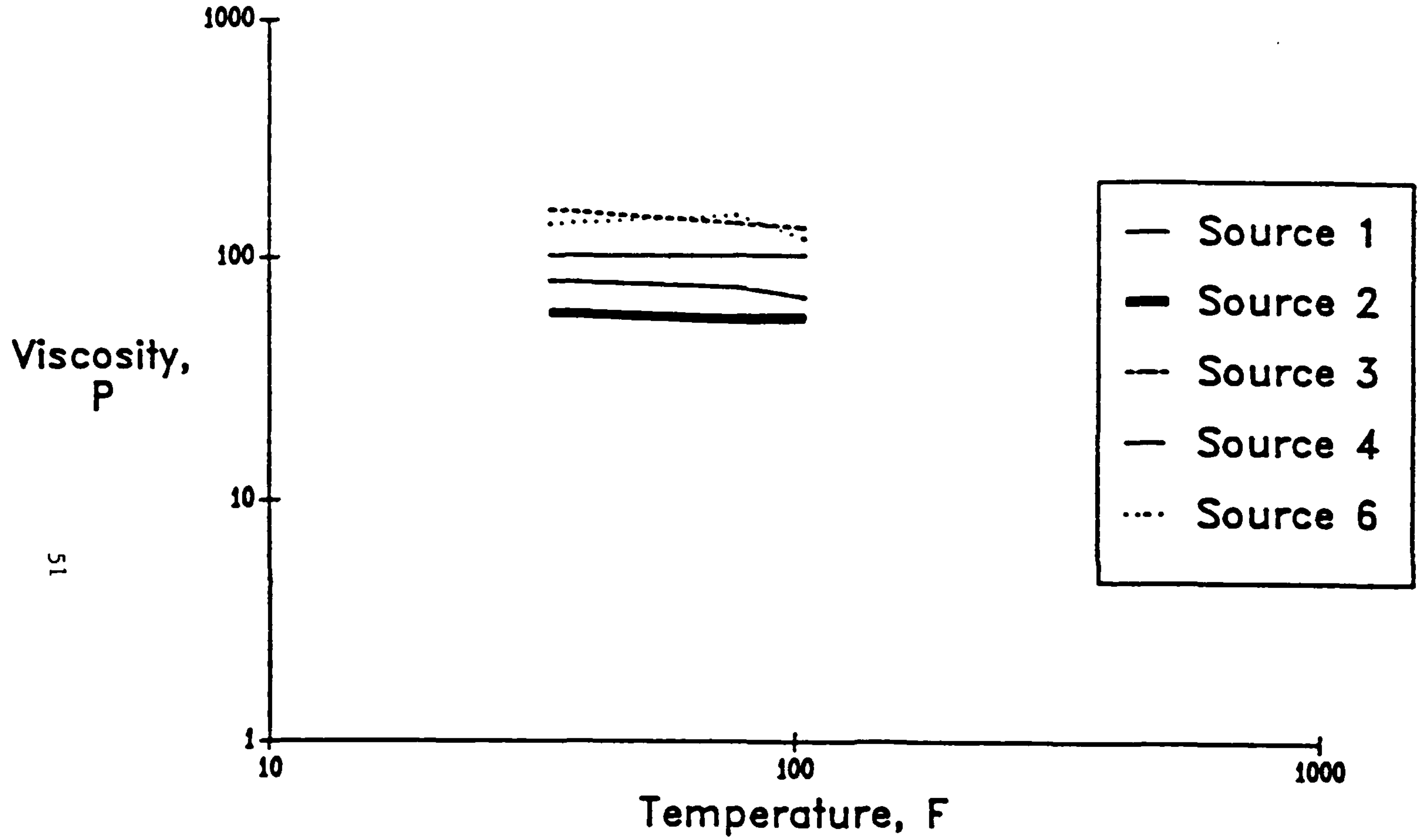


Figure 13 Viscosity-Temperature Relationships for Coal Tar Emulsions

Table 12 Influence of Increasing Additive Content on Viscosity Readings for Stage 2 of Testing Phase 1

	Water Content		
Source	Low	Med	High
1	+	VAR	VAR
2	NC	VAR	NC*
3	DEC	DEC*	DEC*
4	VAR	VAR	NC
5	VAR	DEC	DEC
6	DEC*	DEC*	+

INC - addition of additive increased viscosity reading
DEC - addition of additive decreased viscosity reading
VAR - addition of additive varied viscosity reading
NC - addition of additive produced no change in viscosity reading
\+ - unable to make comparison due to inability to test material
* - comparison based on two levels of additive only

Water Content
Low = 20 gal/100 gal CT
Medium = 55 gal/100 gal CT
High = 90 gal/100 gal CT

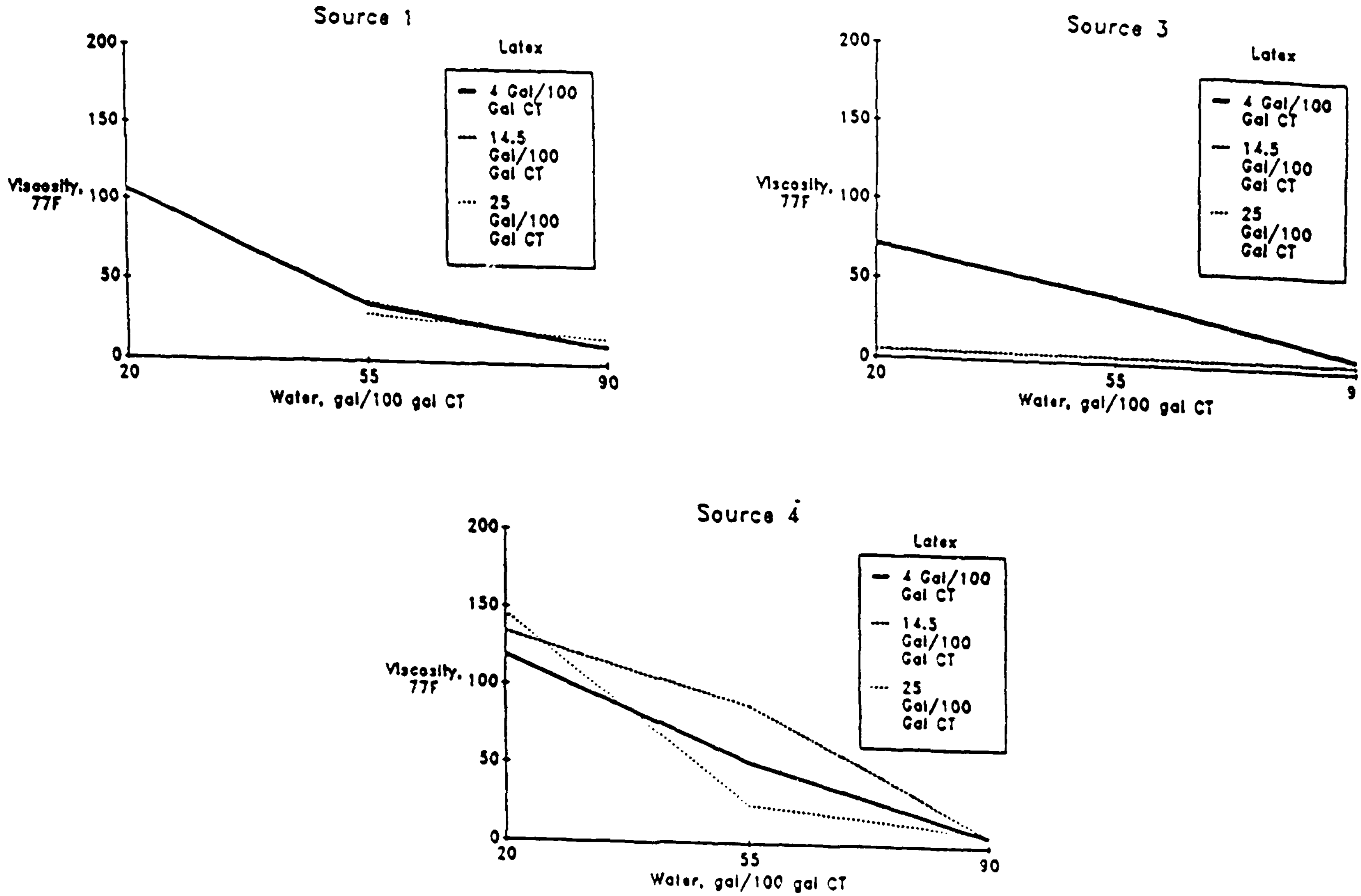


Figure 14 Viscosity Versus Water and Content for Sources 1, 3, 4 (A-B Latex Additives)

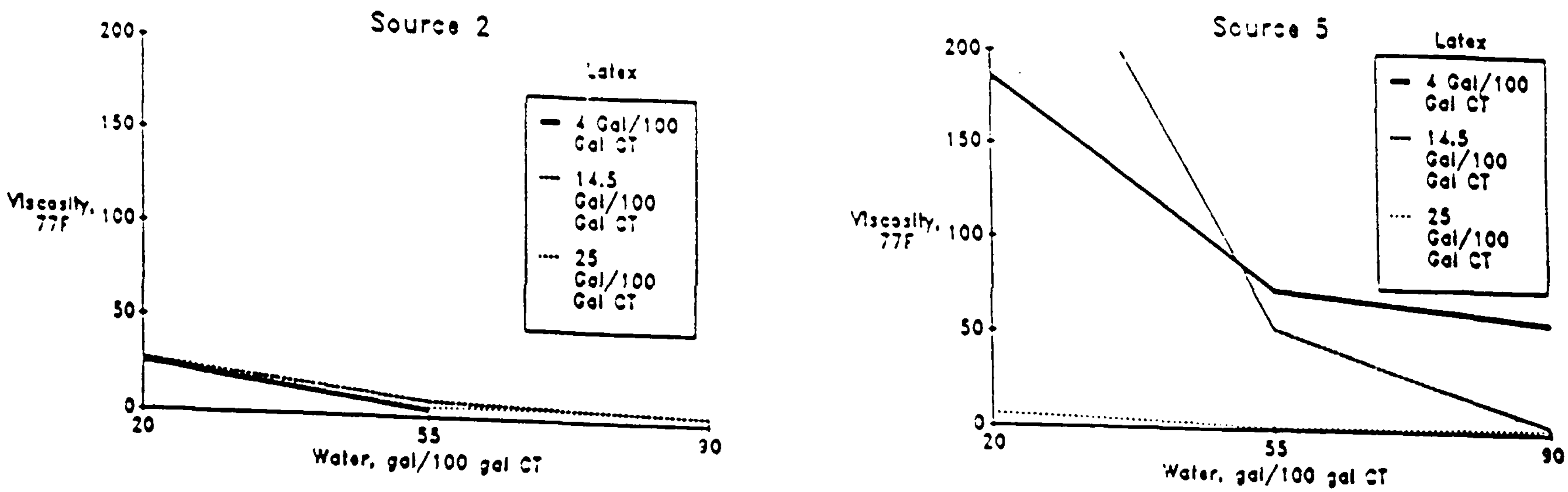


Figure 15 Viscosity Versus Water Content for Sources 2 and 5

Table 13 Influence of Increasing Water Content on Viscosity Readings for Stage 2 of Testing Phase 1

	Additive Content		
Source	Low	Med.	High
1	DEC	DEC*	DEC*
2	DEC*	DEC	DEC
3	DEC	NC	+
4	DEC	DEC	DEC
5	DEC	DEC	DEC
6	+	DEC*	+

INC - addition of water increased viscosity reading
DEC - addition of water decreased viscosity reading
VAR - addition of water varied viscosity reading
NC - addition of water produced no change in viscosity reading
\+ - unable to make comparison due to inability to test material
* - comparison based on two levels of water only

Additive Content
Low = 4.0 gal/100 gal CT
Medium = 14.5 gal/100 gal CT
High = 25.0 gal/100 gal CT

considered is that shown in Figure 16. Figure 16 shows that the sand gradation and shape have a slight effect on the viscosity of the mix.

Phase 2 - Effects of Additive, Water, and Sand Contents on Viscosity Readings. The sections to follow will consider the effects of (1) Additive content, (2) Water content, (3) Sand content on viscosity readings.

Additive: Relationships were developed for three additive contents with and without sand: 4, 14.5, and 25 gal per 100 gal coal tar emulsion. Figure 17 shows viscosity versus total water content for source 1 with no, sand, low sand, and high sand contents. Total water content includes the added water plus the water in the additive and coal tar emulsion. Figure 17 shows that viscosity at low water contents is higher at low additive contents; but as the water content increases the viscosity at low additive contents decreases.

Table 14 presents a summary of the effects of increasing additive content on viscosity values. Table 13 shows that, in general, viscosity decreases with an increase in additive content, at each water content independently of sand loading.

Water: Relationships were developed with and without sand for three water contents. The additive contents were 20, 55, and 90 gal per 100 gal coal tar emulsion. Figure 18 shows viscosity versus total water content for source 2 with no sand, low sand, and high sand contents. As before total water content includes the added water plus the water in the additive and coal tar emulsion. The general trend shown in Figure 18 is a decrease in viscosity with an increase in total water content, at each sand and additive content.

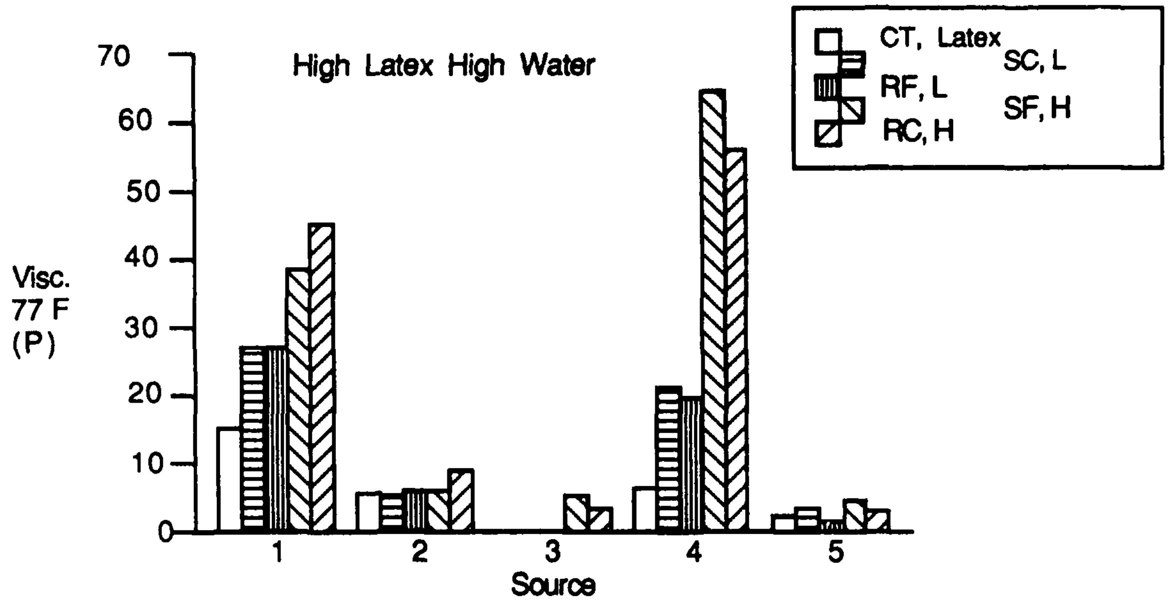
Table 15 presents a summary of the effects of increasing water content on viscosity values. It is clear that there is a decrease in viscosity with increase in water content that is independent of sand and additive content.

Sand: Relationships were developed for three levels of sand content: 2 and 13 lbs per gallon of coal tar emulsion. Figure 17 shows viscosity versus total water content for source 1. Figure 17 shows that viscosity increases at each additive and water content as the sand loading is increased.

Table 16 presents a summary of the effects of increasing sand content on viscosity values; and indicates that, viscosity increases with increasing sand content, independently of water and additive content.

Settling Test

Phase 1: Because the settling apparatus was not set up at this time the settling test was not performed in this phase of testing.



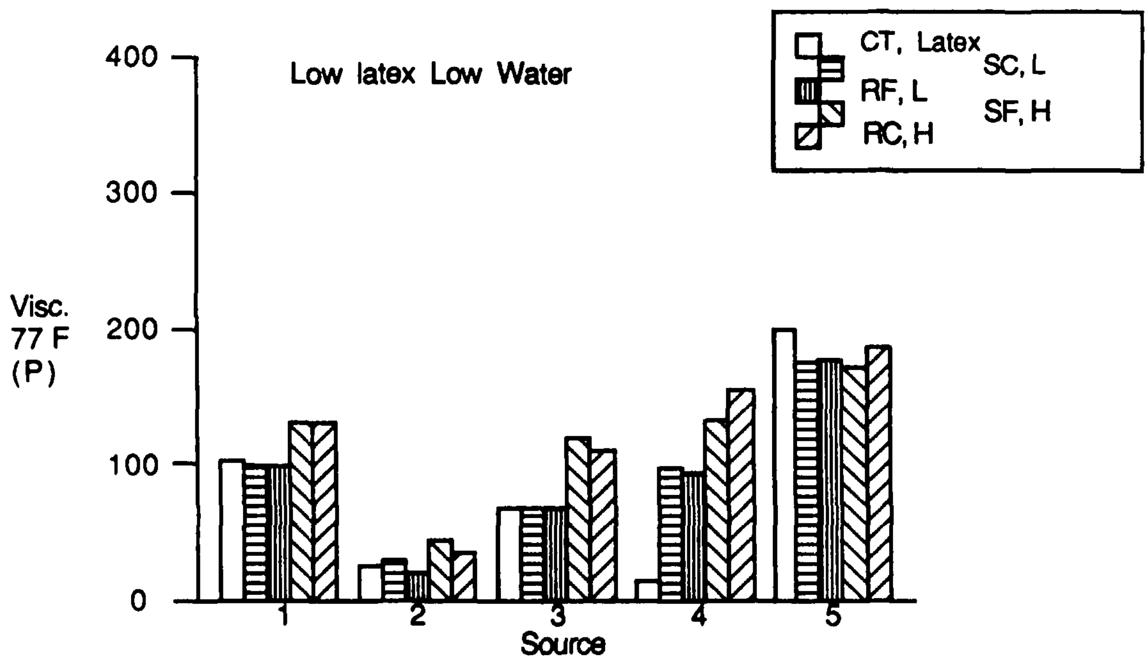
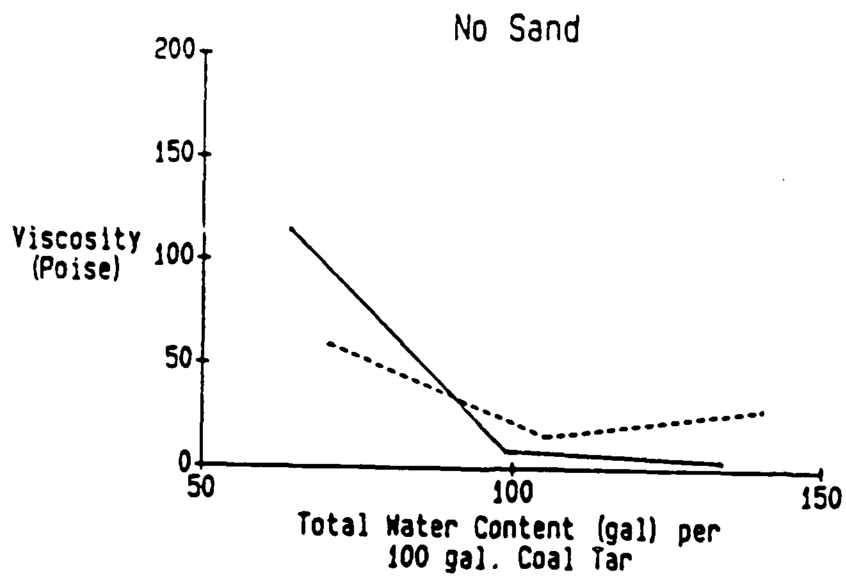
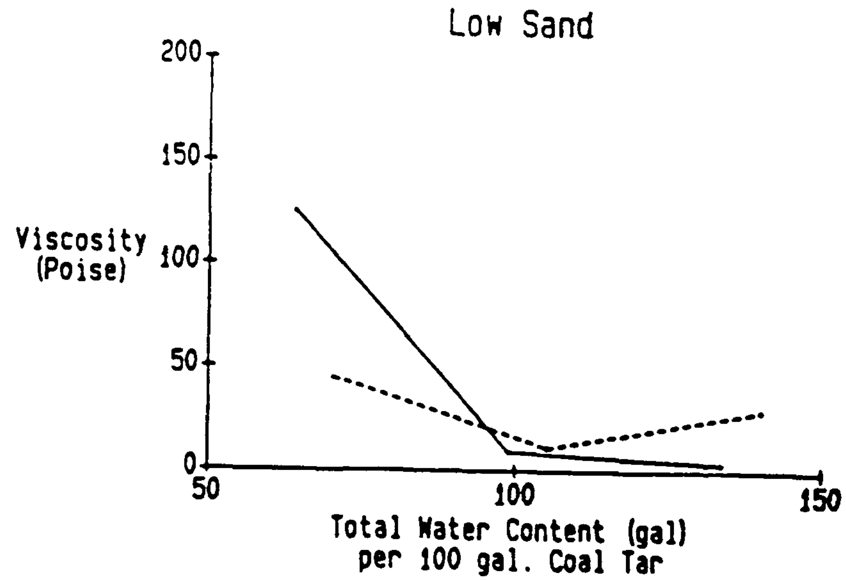
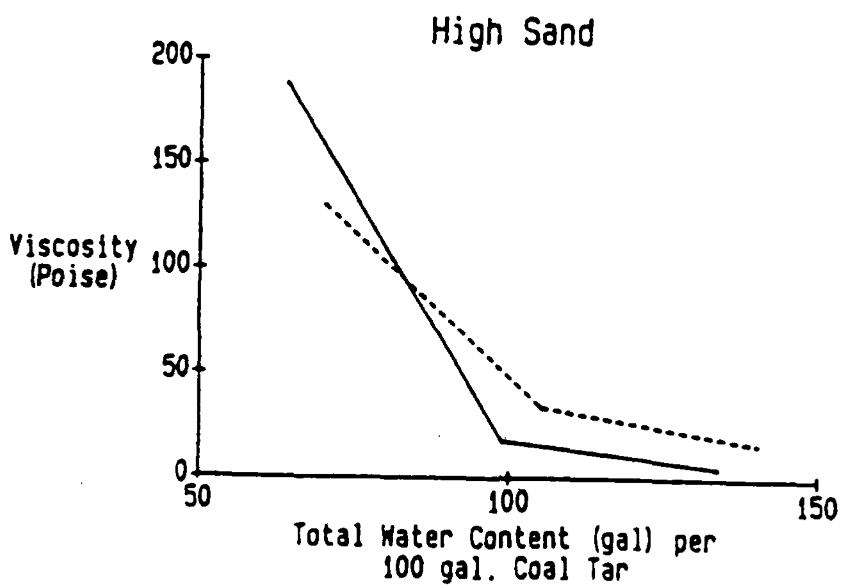


Figure 16: Influence of Sand Gradation and Shape on Viscosity







Legend

Low Additive (4.0g/100g CT) = Solid
Medium Additive (14.5g/100g CT) = Dashed
High Additive (25.0g/100g CT) = Dotted

Figure 17
Source 1, Viscosity Versus
Total Water Content

Table 14 Influence of Increasing Additive Content on Viscosity Values for Testing Phase 2

Source	Sand Content	Water Content Low	Med.	High
1	No	DEC*	INC*	INC*
1	Low	DEC*	NC*	INC*
1	High	DEC*	INC*	INC*
2	No	DEC	DEC	NC*
2	Low	DEC	DEC	*
2	High	DEC	DEC	DEC
3	No	DEC	DEC*	DEC*
3	Low	VAR	NC*	NC*
3	High	DEC*	INC*	INC*
4	No	VAR	INC	VAR
4	Low	INC	INC	VAR
4	High	INC*	VAR	VAR
6	No	+	DEC	DEC*
6	Low	+	DEC	INC*
6	High	+	INC*	DEC*

INC - Addition of additive increased viscosity reading
DEC - Addition of additive decreased viscosity reading
VAR - Addition of additive varied viscosity reading
NC - Addition of additive produced no change in viscosity reading
* - Indicates trend is based on two levels of additive only
+ - Unable to make comparision due to inability to test material

Sand Content
- No sand
- Low sand content (2 lbs/gal CT)
- High sand content (13 lbs/gal CT)

Water Content
- Low water content (20.0 gal/100 gal CT)
- Medium water content (55.0 gal/100 gal CT)
- High water content (90 gal/100 gal CT)

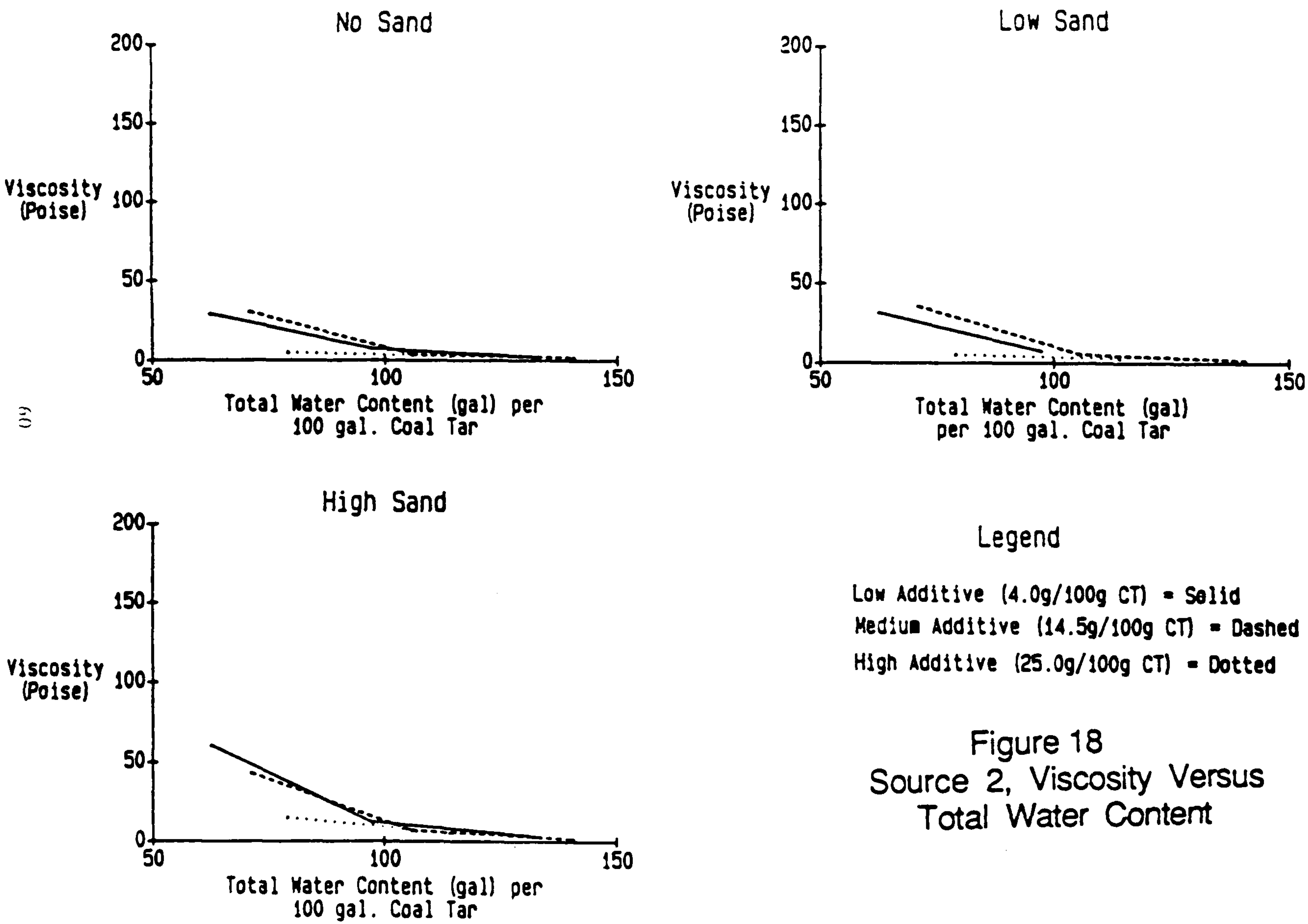


Figure 18
Source 2, Viscosity Versus
Total Water Content

Table 15 Influence of Increasing Water Content on Viscosity Values for Phase 2 Testing

Source	Sand Content	Additive Content Low	Additive Content Med.	Additive Content High
1	No	DEC	VAR	+
1	Low	DEC	VAR	+
1	High	DEC	DEC	+
2	No	DEC	DEC	DEC*
2	Low	DEC*	DEC	DEC*
2	High	DEC	DEC	DEC*
3	No	DEC	DEC	+
3	Low	DEC	DEC	+
3	High	DEC	DEC*	+
4	No	DEC	DEC	DEC
4	Low	DEC	DEC	DEC
4	High	DEC	DEC	DEC*
6	No	DEC*	DEC*	+
6	Low	DEC*	DEC*	+
6	High	DEC*	+	+

INC - Addition of water increased viscosity reading
DEC - Addition of water decreased viscosity reading
VAR - Addition of water varied viscosity reading
NC - Addition of water produced no change in viscosity reading
* - Indicates trend is based on two levels of water only
+ - Unable to make comparision due to inability to test material

Sand Content
No sand
Low sand content (2 lbs/gal CT)
High sand content (13 lbs/gal CT)

Additive Content
Low additive content (4.0 gal/100 gal CT)
Medium additive content (14.5 gal/100 gal CT)
High additive content (25 gal/100 gal CT)

Table 16 Influence of Increasing Sand Content on Viscosity Values for Phase 2 Testing

Source	Additive Content	Water Content Low	Water Content Med.	Water Content High
1	Low	INC	INC	VAR
1	Med.	INC	INC	VAR
1	High	+	+	+
2	Low	INC	INC	NC*
2	Med.	INC	INC	NC
2	High	INC	INC	+
3	Low	INC	INC	NC
3	Med.	INC*	INC	INC
3	High	INC	+	+
4	Low	INC	VAR	INC
4	Med.	VAR	INC	INC
4	High	INC*	INC	INC
6	Low	+	INC	INC
6	Med.	+	INC*	VAR
6	High	+	INC	+

INC - Addition of sand increased viscosity reading
DEC - Addition of sand decreased viscosity reading
VAR - Addition of sand varied viscosity reading
NC - Addition of sand produced no change in viscosity reading
* - Indicates trend is based on two levels of sand only
+ - Unable to make comparision due to inability to test material

Additive Content
L = low additive content (4.0 gal/100 gal CT)
M = medium additive content (14.5 gal/100 gal CT)
H = high additive content (25.0 gal/100 gal CT)

Water Content
L = low water content (20.0 gal/100 gal CT)
M = medium water content (55.0 gal/100 gal CT)
H = high water content (90 gal/100 gal CT)

Phase 2: The following sections will examine the influence of:

(1) Additive content
(2) Water content
(3) Sand content

Additive: Table 17 shows the influence of increasing additive content on settling ratio values. Due to the coagulation of the mix which occurs with high additive contents, many of the mixtures were unable to be evaluated with this test. This made it difficult to distinguish any trends or relationships.

Water: Table 18 shows the influence of increasing water content on settling ratio values. Once again, due to the fact that so many of the mixtures were unable to be evaluated with this test, it was difficult to distinguish any trends or relationships.

Sand: Table 19 shows the influence of increasing sand content on settling ratio values. With the limited data it is difficult to distinguish any trends or relationships.

RATE OF SET AND RESISTANCE TO SCUFFING

Scuff test data are given in Appendix D.

Results of analyses of the data are given in the following paragraphs

Phase 1:

As previously mentioned, Phase 1 of the research program consisted of an experimental plan which was a partial factorial design with two levels for each factor. This means that when two cells are compared, there are actually two factors changing instead of only one. This makes it difficult to distinguish which factor is actually influencing the change in a test result.

The sections to follow will consider the effects of:

(1) Additive content
(2) Water content
(3) Sand content
(4) Sand shape
(5) Sand gradation

on the torque readings. When these comparisons are considered, each relationship has another variable included. For example, when additive, sand and water contents are held constant, the sand shape and gradation vary; or if the sand gradation, shape and additive content are held constant both the water and sand contents vary. The nature of a two factor factorial experiment precludes further separation of these variables.

Table 17 Influence of Increasing Additive Content on Settling Values for Stage 2 Testing

Source	Sand Content	Water Content Low	Water Content Med.	Water Content High
1	No	DEC*	NC*	INC*
1	Low	DEC*	INC*	DEC*
1	High	+	+	+
2	No	INC	INC	DEC*
2	Low	+	INC	DEC*
2	High	+	DEC*	DEC*
3	No	INC*	INC*	DEC*
3	Low	INC*	+	INC*
3	High	+	+	+
4	No	+	+	INC*
4	Low	INC	+	+
4	High	+	+	+
6	No	+	+	INC*
6	Low	+	+	+
6	High	+	+	+

INC - Addition of additive increased settling value
DEC - Addition of additive decreased settling value
VAR - Addition of additive varied settling value
NC - Addition of additive produced no change in settling value
* - Indicates trend is based on two levels of additive only
\+ - Unable to make comparision due to inability to test material

Sand Content

No sand
Low sand content (2 lbs/gal CT)
High sand content (13 lbs/gal CT)

Water Content

Low water content (20.0 gal/100 gal CT)
Medium water content (55.0 gal/100 gal CT)
High water content (90 gal/100 gal CT)

Table 18 Influence of Increasing Water Content on Settling Values for Phase 2 Testing

Source	Sand Content	Additive Content Low	Med.	High
1	No	INC	INC	+
1	Low	INC	VAR	+
1	High	DEC	+	+
2	No	INC	VAR	INC*
2	Low	VAR	DEC*	INC*
2	High	+	DEC*	+
3	No	NC	DEC*	+
3	Low	DEC	+	+
3	High	+	+	+
4	No	INC	+	+
4	Low	INC	+	+
4	High	+	+	+
6	No	+	+	+
6	Low	+	+	+
6	High	+	+	+

INC - Addition of water increased settling value
DEC - Addition of water decreased settling value
VAR - Addition of water varied settling value
NC - Addition of water produced no change in settling value
* - Indicates trend is based on two levels of water only
+ - Unable to make comparision due to inability to test material

Sand Content
- No sand
- Low sand content (2 lbs/gal CT)
- High sand content (13 lbs/gal CT)

Additive Content
- Low additive content (4.0 gal/100 gal CT)
- Medium additive content (14.5 gal/100 gal CT)
- High additive content (25 gal/100 gal CT)

Table 19 Influence of Increasing Sand Content on Settling Values for Phase 2 Testing

Source	Additive Content	Water Content Low	Water Content Med.	Water Content High
1	Low	INC*	INC	VAR
1	Med.	INC*	INC*	DEC*
1	High	+	+	+
2	Low	+	NC*	INC
2	Med.	+	INC	NC
2	High	DEC*	INC	+
3	Low	INC*	INC*	NC*
3	Med.	+	+	INC*
3	High	DEC*	+	+
4	Low	NC*	INC*	INC*
4	Med.	+	+	+
4	High	+	+	+
6	Low	+	+	+
6	Med.	+	+	+
6	High	+	+	+

INC - Addition of sand increased settling value
DEC - Addition of sand decreased settling value
VAR - Addition of sand varied settling value
NC - Addition of sand produced no change in settling value
* - Indicates trend is based on two levels of sand only
+ - Unable to make comparision due to inability to test material

Additive Content
Low additive content (4.0 gal/100 gal CT)
Medium additive content (14.5 gal/100 gal CT)
High additive content (25.0 gal/100 gal CT)

Water Content
Low water content (20.0 gal/100 gal CT)
Medium water content (55.0 gal/100 gal CT)
High water content (90 gal/100 gal CT)

Additive: Relationships were developed for two additive contents: 4.0 and 25.0 gal per 100 gal coal tar emulsion, while the water content was held constant. Figures 19 and 20 present plots of torque versus time for coal tar sources 2 and 5 respectively. In both cases the water content is held constant and the additive content varies. The other variables allowed to change in this relationship are the sand content and the sand gradation.

Tables 20 and 21 summarize the results for scuff resistance testing of Phase 1. In this table the water content, sand content and sand type (shape) are held constant and the effects of additive content are considered at 4 and 24 hours of cure time. It should be noted that the effects of sand gradation are not being considered. It is evident that there are no trends in this relationship. An explanation is warranted concerning the "no changes" (NC) shown in the 24 hour curing section. This was due to the torque wrench reaching its maximum capacity, so all or most tests were recorded as 150 inch-pounds of torque.

Water: Relationships were developed for two water contents, 20.0 and 90.0 gal/100 gal coal tar emulsion, while the additive content was held constant. Figures 21 and 22 present plots of torque versus time for material sources 1 and 3, respectively. In both cases the additive content is held constant and the water content varies. The other variables which are changing are the sand content and the sand gradation. It can be seen that there is no relationship strictly due to the variation in water content.

Tables 22 and 23 presents a summary of the results for scuff resistance testing of Phase 1, in which the additive content, sand content and sand type are held constant and the water content is allowed to vary. This relationship is shown at 4 hours and 24 hours of cure time. It should be noted that the effects of sand gradation are not being considered. It is evident that there are no trends in this relationship. Once again the "no changes" (NC) shown with an asterisk in the 24 hour curing section, are due to the torque wrench reaching its maximum capacity.

Sand Content: Relationships were developed for two sand contents, 2.0 and 13.0 lbs per 100 gal coal tar emulsion, while the additive and the water contents were held constant. Figures 23 and 24 represents plots of torque versus time for coal tar sources 1 and 2, respectively. In both cases the additive and water contents are held constant and the sand content varies. The other variable which is changing in this relationship is the sand gradation. Figure 24 shows the erratic tendency of the torque values at 1 through 4 hours of curing. In general the torque of a low sand content mixture starts off higher than that of a high sand content mixture. This appears to be due to the sand acting as a friction reducer in the high sand content mixture. As the material starts to harden, the torque of the high sand content mixture exceeds that of the low sand content mixture.

Tables 24 and 25 summarize the results for scuff resistance testing of Phase 1. In this table the additive content, water content and sand

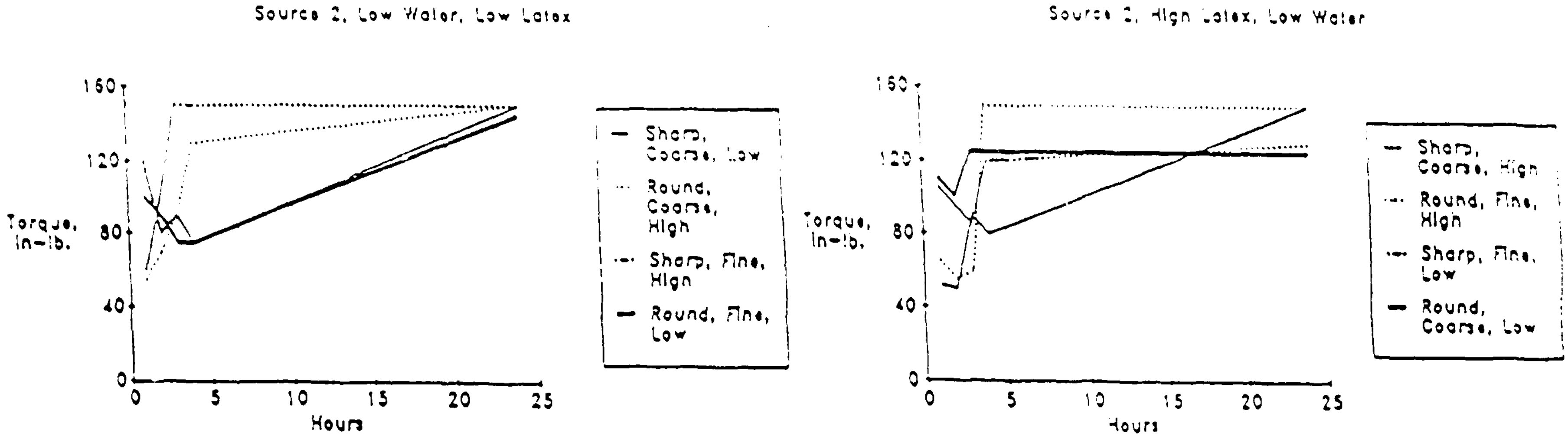


Figure 19 Torque Versus Time for Source 2 with Varying Additive Contents

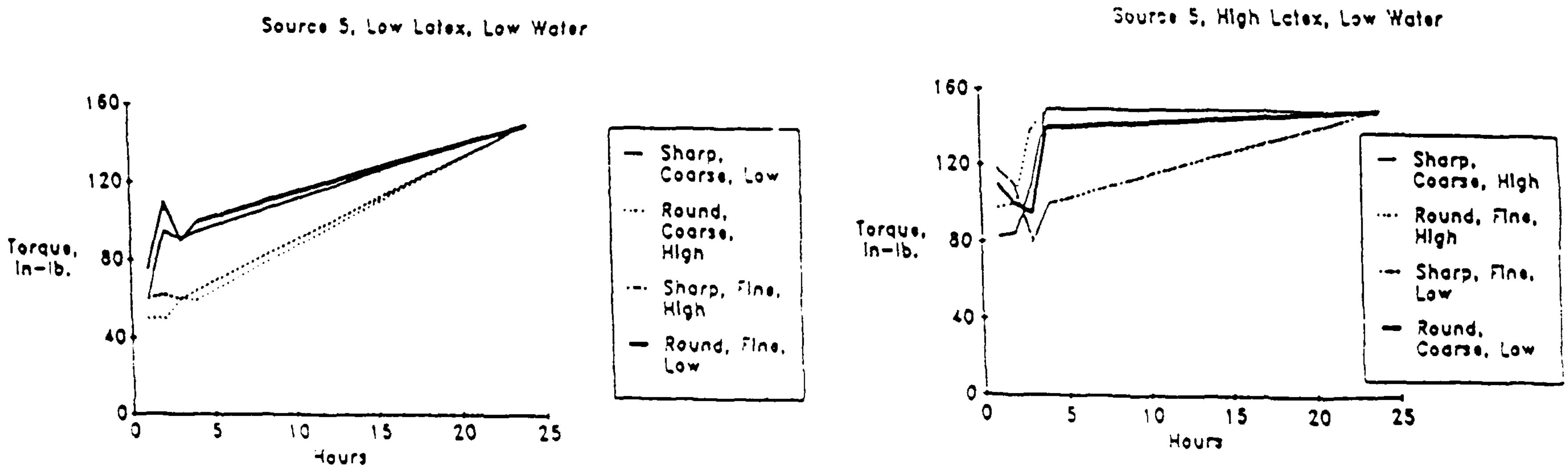


Figure 20 Torque Versus Time for Source 5 with Varying Additive Contents

Table 20 Influence of Increasing Additive Content on Torque Readings for Phase 1 Testing - 4 Hour Cure

		Water Content			
		Low		High	
Source	Sand Type	Low Sand Content	High Sand Content	Low Sand Content	High Sand Content
1	Round	*	*	NC	INC
1	Angular	*	*	INC	INC
2	Round	INC	INC	*	*
2	Angular	INC	DEC	*	*
3	Round	NC	NC	*	*
3	Angular	NC	INC	*	*
4	Round	*	*	NC	DEC
4	Angular	*	*	NC	DEC
5	Round	INC	INC	*	*
5	Angular	NC	INC	*	*

INC = addition of additive increased torque reading
DEC = addition of additive decreased torque reading
NC = addition of additive had no change on torque reading
* = unable to make comparision due to inability to test material

Table 21 Influence of Increasing Additive Content on Torque Readings for Phase 1 Testing - 24 Hour Cure

		Water Content			
		Low		High	
Source	Sand Type	Low Sand Content	High Sand Content	Low Sand Content	High Sand Content
1	Round	*	*	NC	NC
1	Angular	*	*	DEC	NC
2	Round	DEC	NC	*	*
2	Angular	DEC	NC	*	*
3	Round	INC	NC	*	*
3	Angular	NC	NC	*	*
4	Round	*	*	NC	NC
4	Angular	*	*	NC	NC
5	Round	NC	NC	*	*
5	Angular	NC	NC	*	*

INC = addition of additive increased torque reading
DEC = addition of additive decreased torque reading
NC = addition of additive had no change on torque reading
* = unable to make comparision due to inability to test material

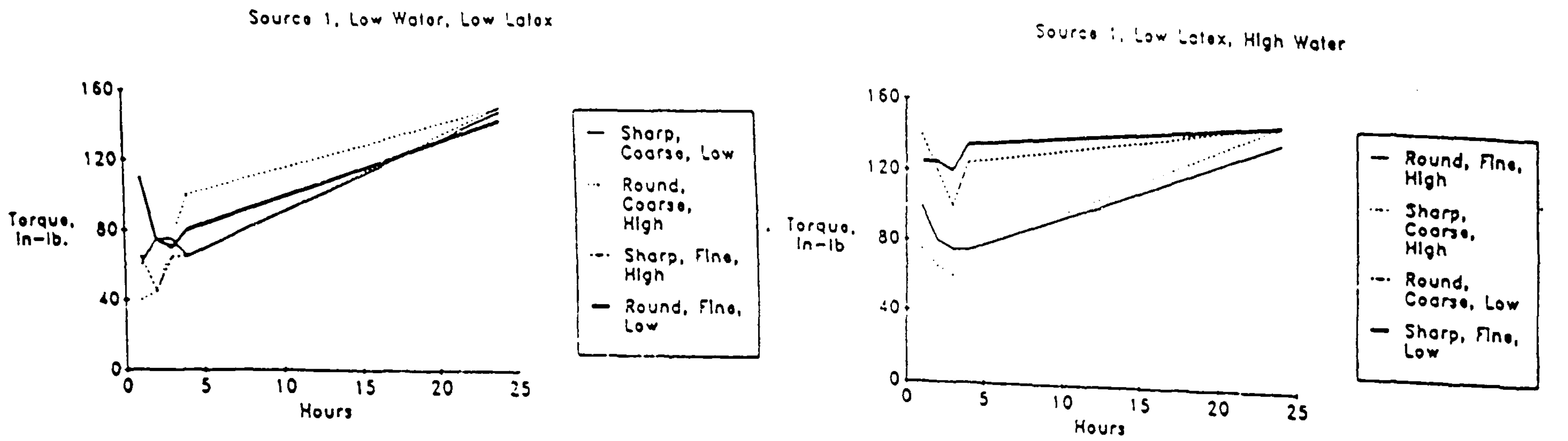


Figure 21 Torque Versus Time for Source 1 wth Varying Water Contents

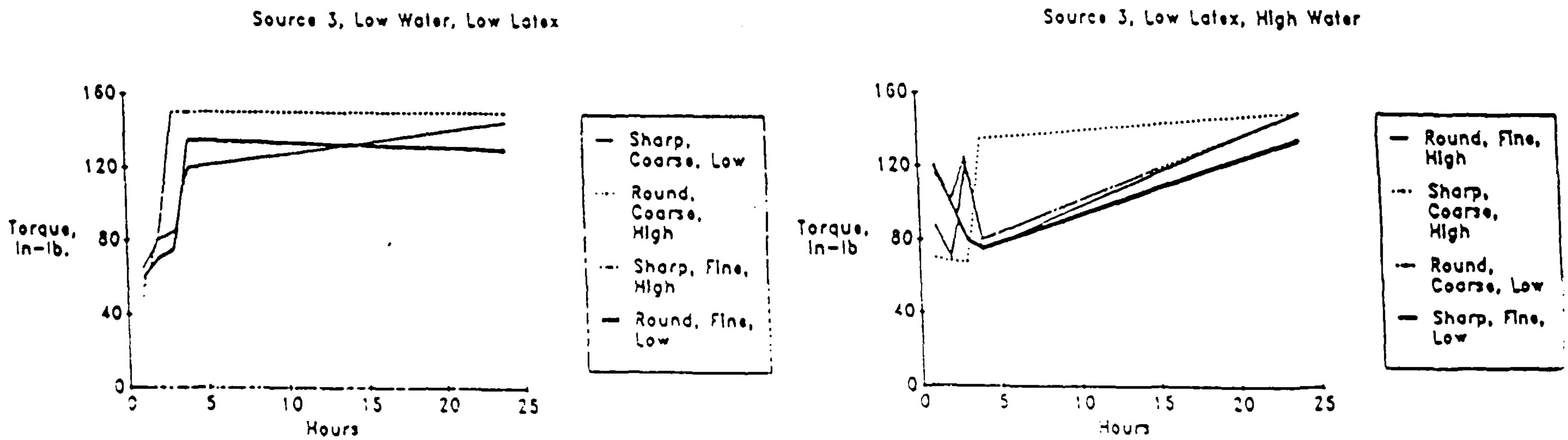


Figure 22 Torque Versus Time for Source 3 with Varying Water Contents

Table 22 Influence of Increasing Water Content on Torque Readings for Phase 1 Testing - 4 Hour Cure

		Additive Content			
		Low		High	
Source	Sand Type	Low Sand Content	High Sand Content	Low Sand Content	High Sand Content
1	Round	INC	DEC	*	*
1	Angular	INC	NC	*	*
2	Round	*	*	DEC	NC
2	Angular	*	*	NC	INC
3	Round	DEC	DEC	*	*
3	Angular	DEC	DEC	*	*
4	Round	INC	NC	*	*
4	Angular	NC	INC	*	*
5	Round	NC	INC	*	*
5	Angular	NC	NC	*	*

INC = addition of water increased torque reading
DEC = addition of water decreased torque reading
NC = addition of water had no change on torque reading
* = unable to make comparision due to inability to test material

Table 23 Influence of Increasing Water Content on Torque Readings for Phase 1 Testing - 24 Hour Cure

		Additive Content			
		Low		High	
Source	Sand Type	Low Sand Content	High Sand Content	Low Sand Content	High Sand Content
1	Round	NC	NC	*	*
1	Angular	NC	NC	*	*
2	Round	*	*	NC	DEC
2	Angular	*	*	NC	DEC
3	Round	INC	NC	*	*
3	Angular	NC	NC	*	*
4	Round	NC	NC	*	*
4	Angular	NC	NC	*	*
5	Round	NC	NC	*	*
5	Angular	NC	NC	*	*

INC = addition of water increased torque reading
DEC = addition of water decreased torque reading
NC = addition of water had no change on torque reading
* = unable to make comparision due to inability to test material

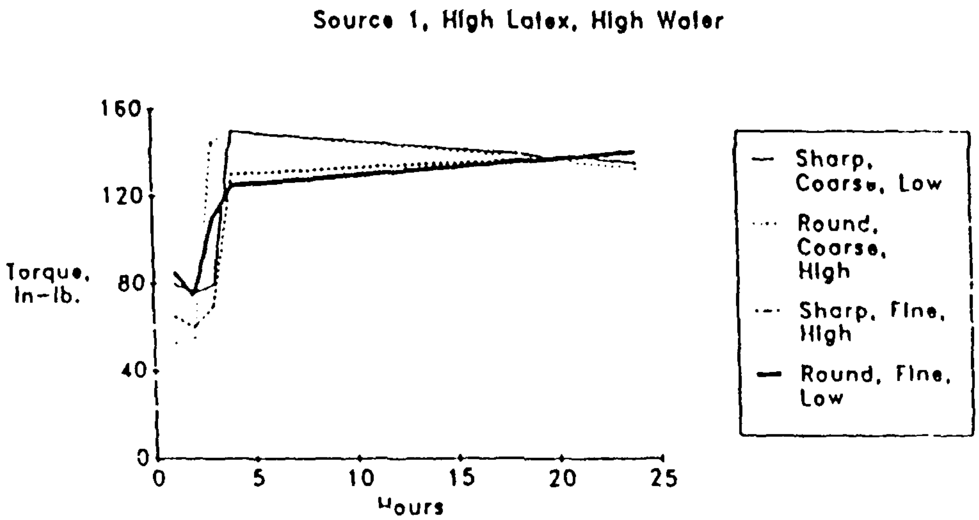


Figure 23 Torque Versus Time for Source 1

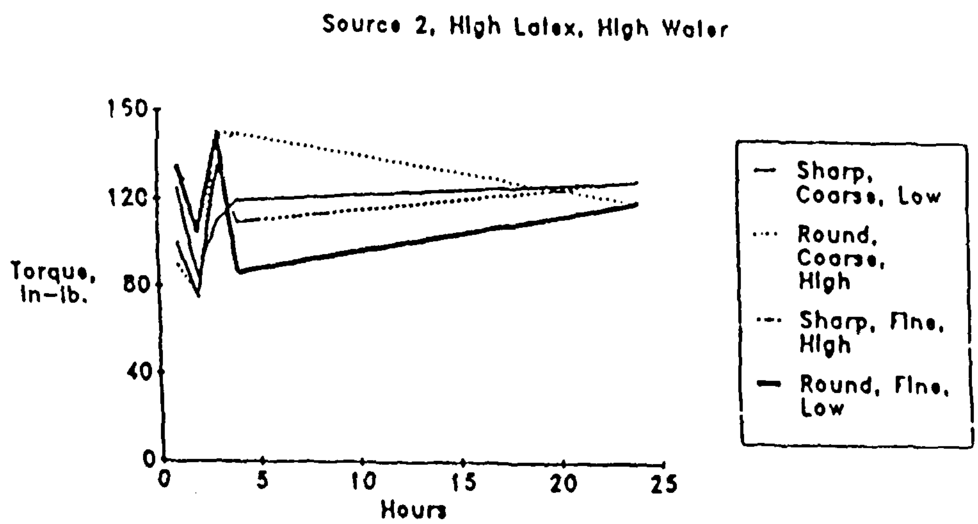


Figure 24 Torque Versus Time for Source 2

Table 24 Influence of Increasing Sand Content on Torque Readings for Phase 1 Testing - 4 Hour Cure

		Water Content			
		Low		High	
Source	Sand Type	Low Additive Content	High Additive Content	Low Additive Content	High Additive Content
1	Round	INC	*	DEC	INC
1	Angular	NC	*	DEC	DEC
2	Round	INC	INC	*	INC
2	Angular	INC	DEC	*	NC
3	Round	INC	INC	NC	*
3	Angular	INC	NC	INC	*
4	Round	INC	*	INC	NC
4	Angular	INC	*	INC	DEC
5	Round	DEC	NC	NC	*
5	Angular	DEC	INC	NC	*

INC = addition of sand increased torque reading
DEC = addition of sand decreased torque reading
NC = addition of sand had no change on torque reading
* = unable to make comparision due to inability to test material

Table 25 Influence of Increasing Sand Content on Torque Readings for Phase 1 Testing - 24 Hour Cure

		Water Content			
		Low		High	
Source	Sand Type	Low Additive Content	High Additive Content	Low Additive Content	High Additive Content
1	Round	NC	*	NC	NC
1	Angular	NC	*	NC	NC
2	Round	INC	NC	*	NC
2	Angular	INC	NC	*	NC
3	Round	INC	NC	NC	*
3	Angular	NC	NC	INC	*
4	Round	NC	*	NC	NC
4	Angular	NC	*	NC	NC
5	Round	NC	NC	NC	*
5	Angular	NC	NC	NC	*

INC = addition of sand increased torque reading
DEC = addition of sand decreased torque reading
NC = addition of sand had no change on torque reading
* = unable to make comparision due to inability to test material

type are held constant and the influence of sand content is considered at 4 hours and 24 hours of cure time. It should be noted that the effects of sand gradation are not considered. A general relationship can be seen at 4 hours of cure time. This relationship is with the increase in sand content, there is an increase in the torque value. Once again the "no changes" (NC) shown with an asterisk in the 24 hour curing section, are due to the torque wrench reaching its maximum capacity.

Sand Shape: Relationships were developed for two sand shapes, round and angular, while the sand and water contents were held constant.

Tables 26 and 27 present a summary of results for scuff resistance testing of Phase 1, holding the additive, sand, and water contents constant and varying the sand shape. This relationship is shown at 4 hours and 24 hours of cure time. It should be noted that the effects of sand gradation are not being considered. It is evident there are no trends with respect to the shape.

Sand Gradation: Data was compared for two sand gradations, fine and coarse, while the sand and additive contents were held constant.

Tables 28 and 29 represents a summary the results for scuff resistance testing of Phase 1, holding the additive, sand, and water contents constant and varying the sand gradation. The data is shown at 4 hours and 24 hours of cure time. It should be noted that the effects of sand shape was not being considered. It is evident there are no trends in this data. Once again "no changes" (NC) shown in the 24 hour curing section, are due to the torque wrench reaching its maximum capacity, so all or most tests were recorded as 150 inch-pounds of torque.

Phase 2

After completion of Phase 1, it was evident that several modifications needed to be made in the test procedure and the equipment used in the scuff resistance testing. These modifications included: (1) a torque wrench with a capacity of 300 inch-pounds, (2) test reading taken at 8 hours, and (3) the incorporation of an additional level of water and additive in the test matrix.

These modifications would make the test results more meaningful. By using a torque wrench with a higher capacity, the test measurements could further differentiate between final scuff resistance values. The additional test reading and level of water and additive was necessary to further understand the data.

The sections to follow will consider the effects of:

(1) Additive content,
(2) Water content, and
(3) Sand content

Table 26 Influence of Sand Shape on Torque Readings for Phase 1 Testing - 4 Hour Cure

		Water Content			
		Low		High	
Source	Sand Content	Low Additve Content	High Additve Content	Low Additve Content	High Additve Content
1	Low	NC	*	NC	INC
1	High	DEC	*	NC	DEC
2	Low	NC	NC	*	INC
2	High	INC	DEC	*	DEC
3	Low	NC	NC	NC	*
3	High	NC	INC	INC	*
4	Low	NC	*	NC	NC
4	High	DEC	*	NC	DEC
5	Low	NC	DEC	NC	*
5	High	NC	NC	NC	*

INC = increase in surface texture of material increased torque reading
DEC = increase in surface texture of material decreased torque reading
NC = increase in surface texture of material had no change on torque reading
* = unable to make comparision due to inability to test material

Table 27 Influence of Sand Shape on Torque Readings for Phase 1 Testing - 24 Hour Cure

		Water Content			
		Low		High	
Source	Sand Content	Low Additve Content	High Additve Content	Low Additve Content	High Additve Content
1	Low	NC	*	NC	NC
1	High	NC	*	NC	NC
2	Low	NC	NC	*	NC
2	High	NC	NC	*	NC
3	Low	NC	NC	INC	*
3	High	NC	NC	NC	*
4	Low	NC	*	NC	NC
4	High	NC	*	NC	NC
5	Low	NC	NC	NC	*
5	High	NC	NC	NC	*

INC = increase in surface texture of material increased torque reading
DEC = increase in surface texture of material decreased torque reading
NC = increase in surface texture of material had no change on torque reading
* = unable to make comparision due to inability to test material

Table 28 Influence of Sand Gradation on Torque Readings for Phase 1 Testing - 4 Hour Cure

Source	Sand Content	Water Content Low: Low Additive Content	Water Content Low: High Additive Content	Water Content High: Low Additive Content	Water Content High: High Additive Content
1	Low	NC	*	NC	INC
1	High	INC	*	NC	INC
2	Low	NC	NC	*	INC
2	High	DEC	DEC	*	INC
3	Low	NC	NC	NC	*
3	High	NC	DEC	INC	*
4	Low	NC	*	NC	NC
4	High	INC	*	NC	INC
5	Low	NC	INC	NC	*
5	High	NC	NC	NC	*

INC = increase in coarseness of material increased torque reading
DEC = increase in coarseness of material decreased torque reading
NC = increase in coarseness of material had no change on torque reading
* = unable to make comparision due to inability to test material

Table 29 Influence of Sand Gradation on Torque Readings for Phase 1 Testing - 24 Hour Cure

		Water Content			
		Low		High	
Source	Sand Content	Low Additive Content	High Additive Content	Low Additive Content	High Additive Content
1	Low	NC	*	NC	NC
1	High	NC	*	NC	NC
2	Low	NC	NC	*	NC
2	High	NC	NC	*	NC
3	Low	NC	NC	INC	*
3	High	NC	NC	NC	*
4	Low	NC	*	NC	NC
4	High	NC	*	NC	NC
5	Low	NC	NC	NC	*
5	High	NC	NC	NC	*

INC = increase in coarseness of material increased torque reading
DEC = increase in coarseness of material decreased torque reading
NC = increase in coarseness of material had no change on torque reading
* = unable to make comparision due to inability to test material

on the torque readings. The results of the scuff resistance testing of phase 2, are presented under these headings.

Additive: Data was compared for three additive contents while holding the sand and water contents constant. The additive contents were 4, 14.5, and 25 gal per 100 gal coal tar emulsion. Figure 25 shows plots of torque versus time for coal tar source 1 with high sand content. Figure 26 presents a plot of torque versus additive content at 4, 8, and 24 hours of cure time for coal tar source 2 with low sand content. From the variation seen in these two figures, it would appear that the torque is related to all three variables and not just the additive content.

Tables 30, 31 and 32 summarize the results for scuff resistance for Phase 2 by holding the sand and water contents constant, and showing how an increase in additive content affects the torque reading Because of the extreme fluctuation in the test results from 1 to 3 hours, the effects of additive content are only considered at 4, 8, and 24 hours of cure time. It is evident there are no trends in this data.

Water: Data was compared for three water contents while holding the sand and additive contents constant. The water contents were 20, 55, and 90 gal per 100 gal coal tar emulsion. Figure 27 shows plots of torque versus time for coal tar source 2 with low sand content. Figure 28 plots torque versus water content at 4, 8, and 24 hours of cure time for coal tar source 4 with low sand content. From the variation seen in these two figures, it would appear that the torque is related to all three variables and not just the water content.

Tables 33, 34 and 35 contain a summary of the scuff resistance testing for Phase 2, holding the sand and water contents constant, and varying the additive. Because of the extreme fluctuation of the test results from 1 to 3 hours, the effects of water content are only considered at 4, 8, and 24 hours of cure time. It is evident there are no trends contained in this data.

Sand: Scuff data was compared for two sand contents while holding the water and additive contents constant. The sand contents were 2.0 and 13 lbs per gal coal tar emulsion. Figure 29 and 30 show plots of torque versus time for coal tar source 2 with low and high sand contents respectively. Once again the erratic tendency of the torque readings from 1 through 3 hours appears to be due to the sand acting as a friction reducer in the high sand content mixtures.

Tables 36, 37 and 38 present a summary of the scuff resistance testing for phase 2, holding the additive and water contents constant, and varying the sand content. Once again because of the extreme fluctuation of the test results from 1 to 3 hours, the effects of sand content are only considered at 4, 8, and 24 hours of cure time. It can be seen from Table 25 that at the 8- and 24- hour cure times, the general tendency of increasing sand content is to increase the torque value. This is not the case at the 4 hour cure time because the material has not set up enough to give an accurate indication of the torque reading.

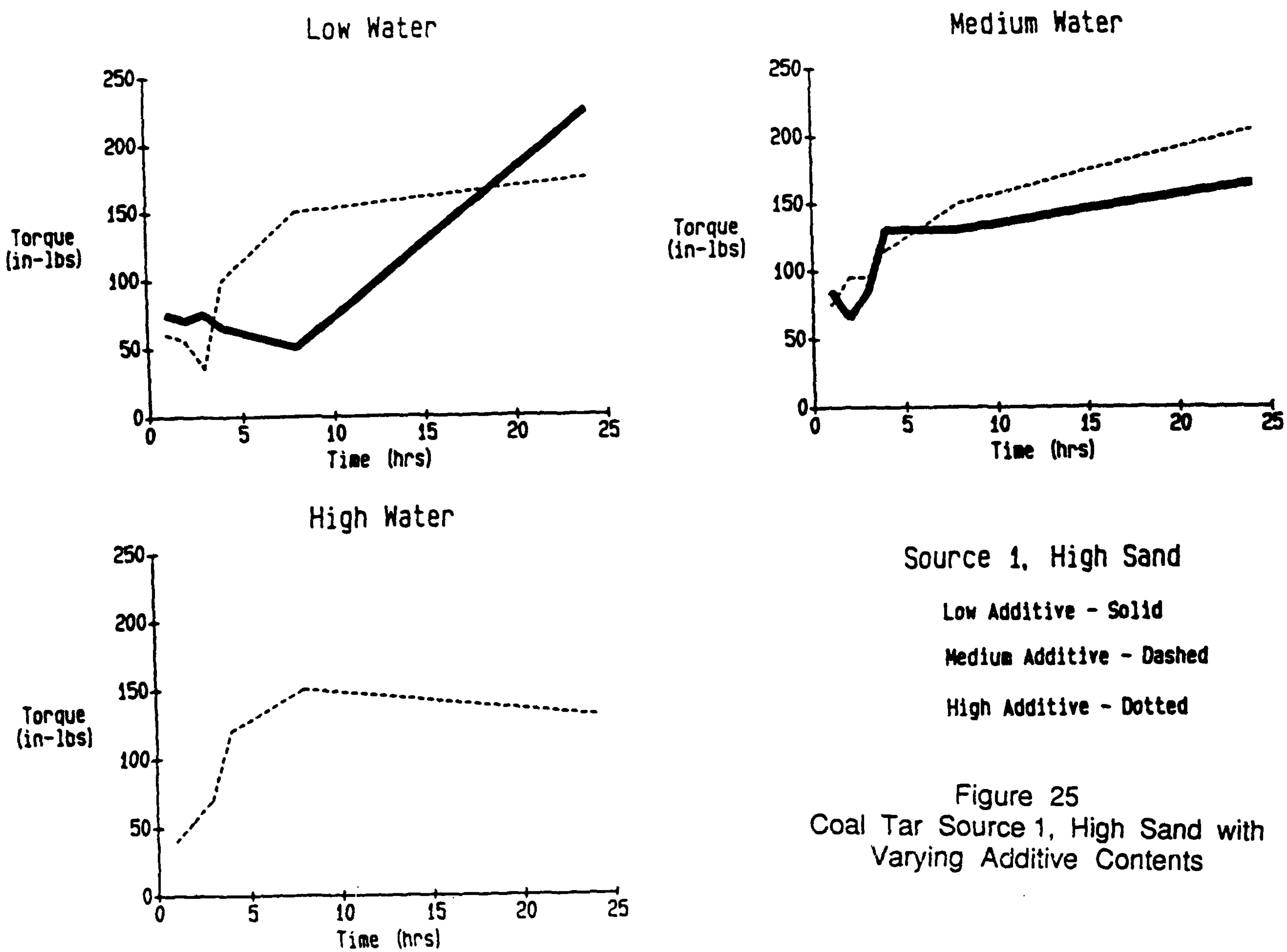
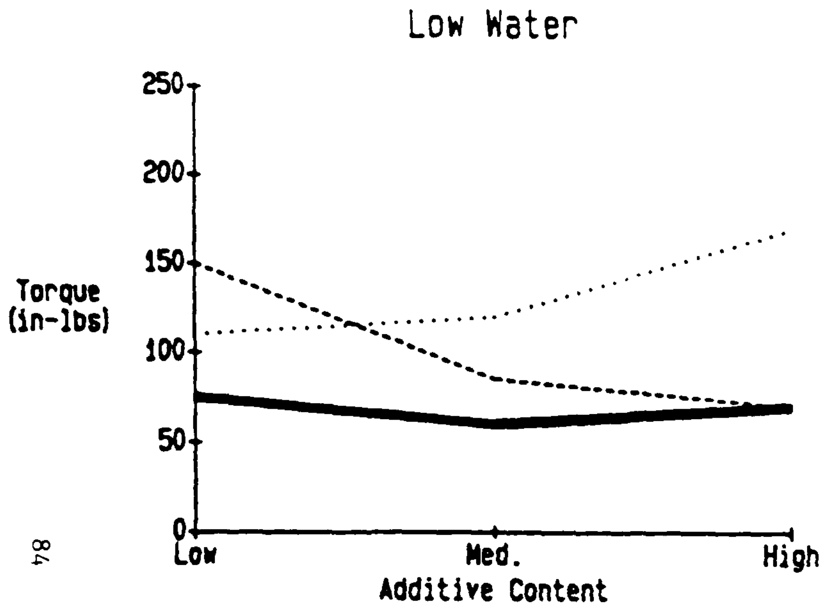
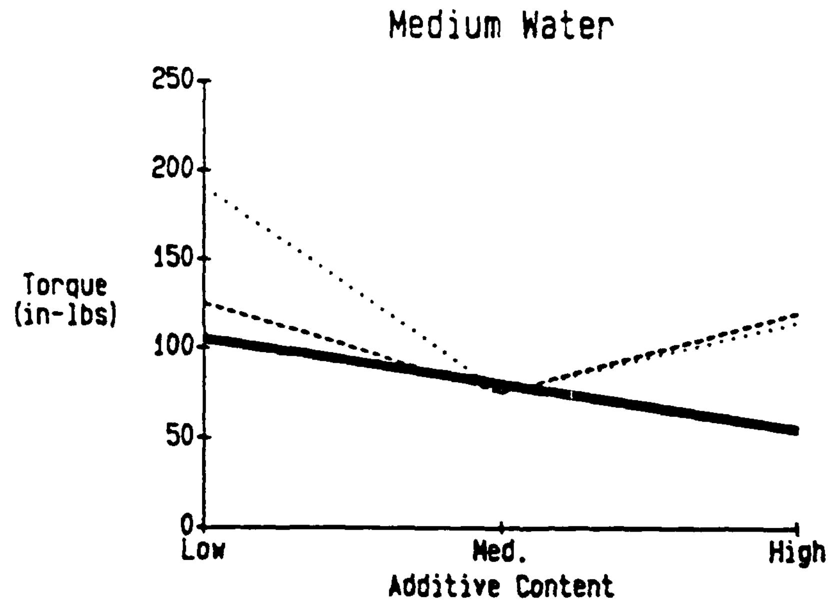
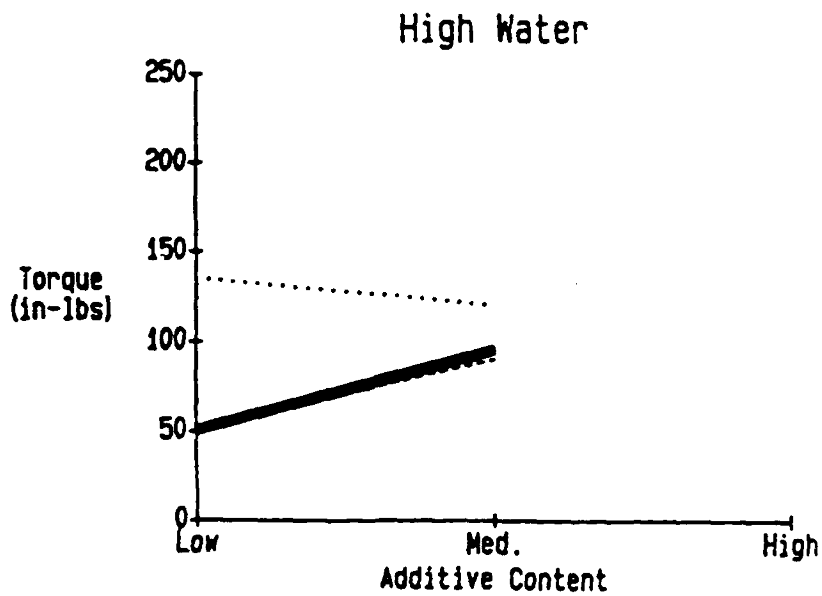


Figure 25
Coal Tar Source 1, High Sand with Varying Additive Contents







Source 2, Low Sand

4 Hour Curing - Solid

8 Hour Curing - Dashed

24 Hour Curing - Dotted

Additive Content

Low = 4.0g/100g CT

Medium = 14.5g/100g CT

High = 25.0g/100g CT

Figure 26
Coal Tar Source 2, Low Sand with Varying Additive Contents

Table 30 Influence of Increasing Additive Content on Torque Readings at 4 Hours of Cure Time for Phase 2 Testing

Source	Sand Content	4 HOUR CURE Low Water Content	Med. Water Content	High Water Content
1	Low	INC*	DEC*	NC*
1	High	INC*	DEC*	+
2	Low	NC	DEC	INC*
2	High	VAR	VAR	INC*
3	Low	VAR	DEC*	DEC*
3	High	INC*	DEC*	NC*
4	Low	INC	INC	INC
4	High	INC*	INC	VAR
6	Low	+	INC	NC*
6	High	+	INC*	INC*

INC - addition of additive increased torque reading
DEC - addition of additive decreased torque reading
VAR - addition of additive varied the torque reading
NC - addition of additive produced no change in the torque reading
* - indicates trend is based on two levels of additive only
+ - unable to make comparision due to inability to test material

Table 31 Influence of Increasing Additive Content on Torque Readings at 8 Hours of Cure Time for Phase 2 Testing

Source	Sand Content	8 HOUR CURE Low Water Content	Med. Water Content	High Water Content
1	Low	INC*	INC*	INC*
1	High	NC*	DEC*	+
2	Low	VAR	VAR	INC*
2	High	DEC	VAR	NC*
3	Low	INC	DEC*	NC*
3	High	NC*	DEC*	INC*
4	Low	VAR	DEC	VAR
4	High	NC*	VAR	NC
6	Low	+	VAR	INC*
6	High	+	DEC*	INC*

INC - addition of additive increased torque reading
DEC - addition of additive decreased torque reading
VAR - addition of additive varied the torque reading
NC - addition of additive produced no change in the torque reading
* - indicates trend is based on two levels of additive only
\+ - unable to make comparision due to inability to test material

Table 32 Influence of Increasing Additive Content on Torque Readings at 24 Hours of Cure Time for Phase 2 Testing

		24 HOUR CURE		
Source	Sand Content	Low Water Content	Med. Water Content	High Water Content
1	Low	DEC*	NC*	NC*
1	High	DEC*	DEC*	+
2	Low	INC	VAR	NC*
2	High	INC	INC	DEC*
3	Low	INC	DEC*	INC*
3	High	DEC*	NC*	NC*
4	Low	DEC	VAR	INC
4	High	INC*	VAR	DEC
6	Low	+	DEC	NC*
6	High	+	DEC*	DEC*

INC - addition of additive increased torque reading
DEC - addition of additive decreased torque reading
VAR - addition of additive varied the torque reading
NC - addition of additive produced no change in the torque reading
* - indicates trend is based on two levels of additive only
+ - unable to make comparision due to inability to test material

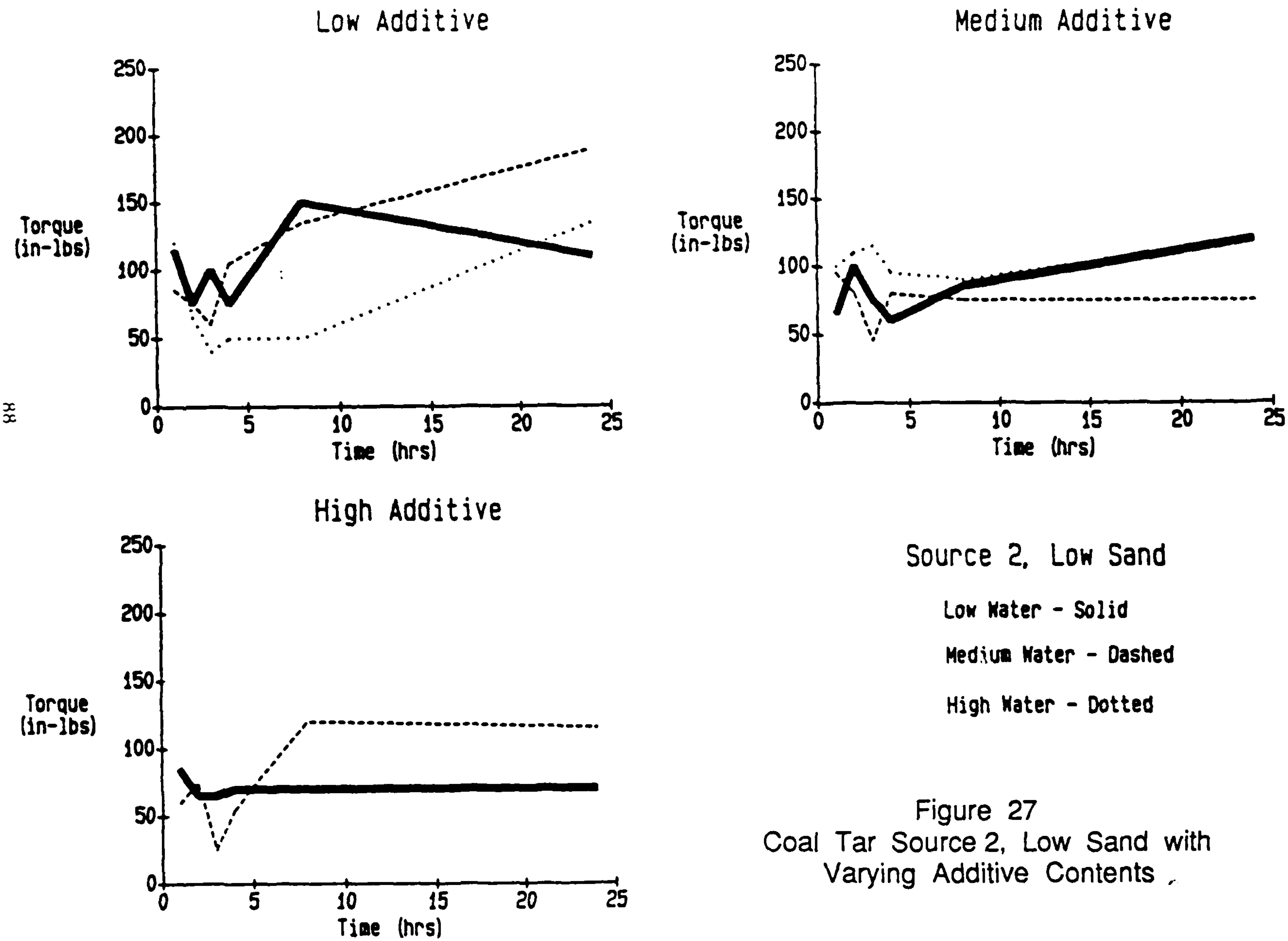


Figure 27
Coal Tar Source 2, Low Sand with Varying Additive Contents

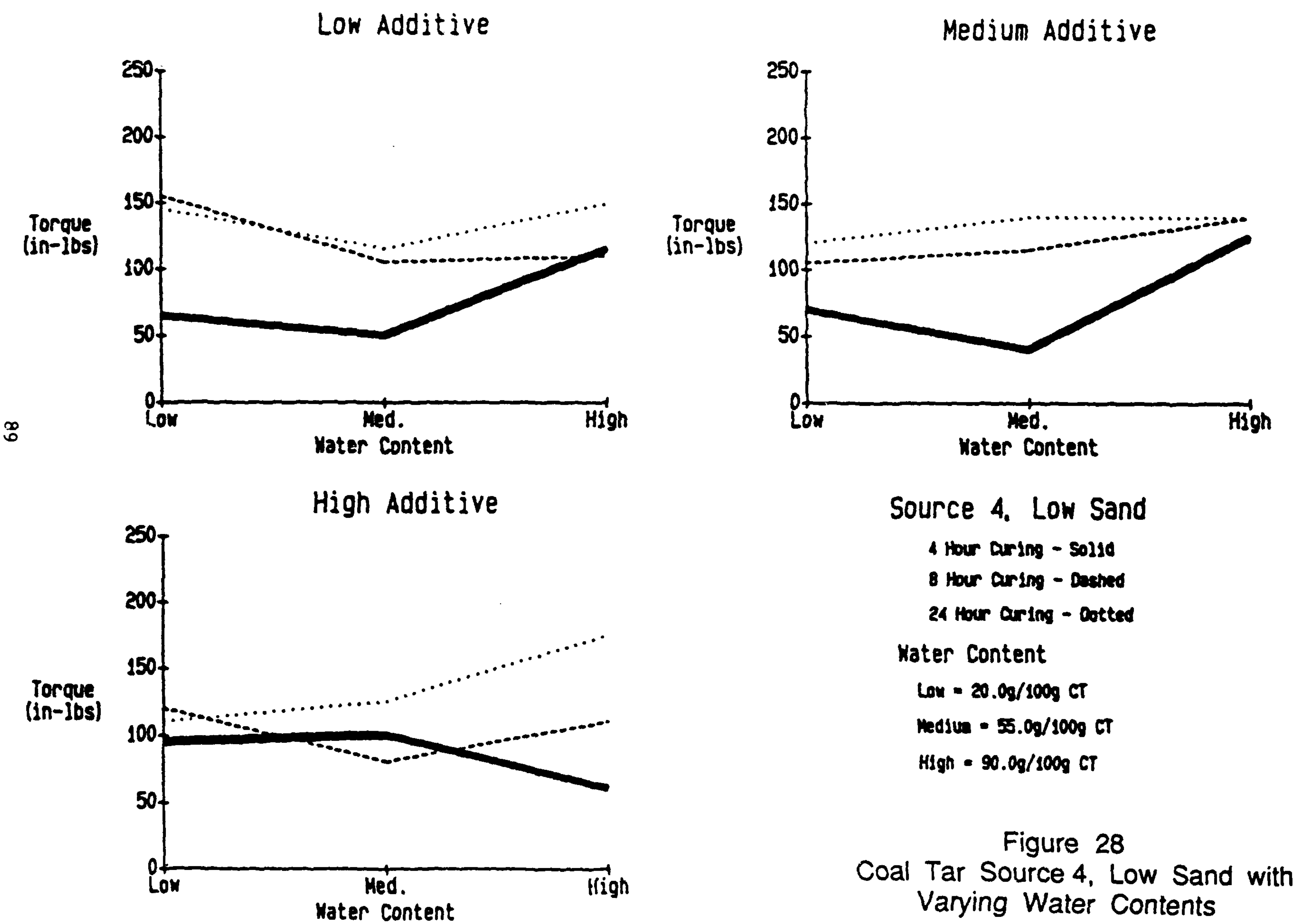


Figure 28
Coal Tar Source 4, Low Sand with Varying Water Contents

Table 33 Influence of Increasing Water Content on Torque Readings at 4 Hours of Cure Time for Phase 2 Testing

Source	Sand Content	4 HOUR CURE Low Additve Content	Med. Additve Content	High Additve Content
1	Low	DEC	DEC	+
1	High	INC*	INC	+
2	Low	VAR	INC	DEC*
2	High	DEC	VAR	NC*
3	Low	VAR	VAR	+
3	High	INC	INC*	+
4	Low	INC	VAR	VAR
4	High	INC	INC	DEC*
6	Low	NC*	NC*	+
6	High	NC*	+	+

INC - addition of water increased torque reading
DEC - addition of water decreased torque reading
VAR - addition of water varied the torque reading
NC - addition of water produced no change in the torque reading
* - indicates trend is based on two levels of water only
+ - unable to make comparision due to inability to test material

Table 34 Influence of Increasing Water Content on Torque Readings at 8 Hours of Cure Time for Phase 2 Testing

Source	Sand Content	8 HOUR CURE Low Additve Content	Med. Additve Content	High Additve Content
1	Low	NC	DEC	+
1	High	INC*	NC	+
2	Low	VAR	NC	INC*
2	High	VAR	VAR	INC*
3	Low	DEC	DEC	+
3	High	NC	INC*	+
4	Low	INC	INC	VAR
4	High	VAR	VAR	NC*
6	Low	DEC*	DEC*	+
6	High	DEC*	+	+

INC - addition of water increased torque reading
DEC - addition of water decreased torque reading
VAR - addition of water varied the torque reading
NC - addition of water produced no change in the torque reading
* - indicates trend is based on two levels of water only
+ - unable to make comparision due to inability to test material

Table 35 Influence of Increasing Water Content on Torque Readings at 24 Hours of Cure Time for Phase 2 Testing

Source	Sand Content	24 HOUR CURE Low Additve Content	Med. Additve Content	High Additve Content
1	Low	DEC	VAR	+
1	High	DEC*	VAR	+
2	Low	VAR	VAR	DEC*
2	High	INC	VAR	NC*
3	Low	INC	VAR	+
3	High	VAR	INC*	+
4	Low	VAR	INC	INC
4	High	VAR	VAR	DEC*
6	Low	DEC*	DEC*	+
6	High	NC*	+	+

INC - addition of water increased torque reading
DEC - addition of water decreased torque reading
VAR - addition of water varied the torque reading
NC - addition of water produced no change in the torque reading
* - indicates trend is based on two levels of water only
+ - unable to make comparision due to inability to test material

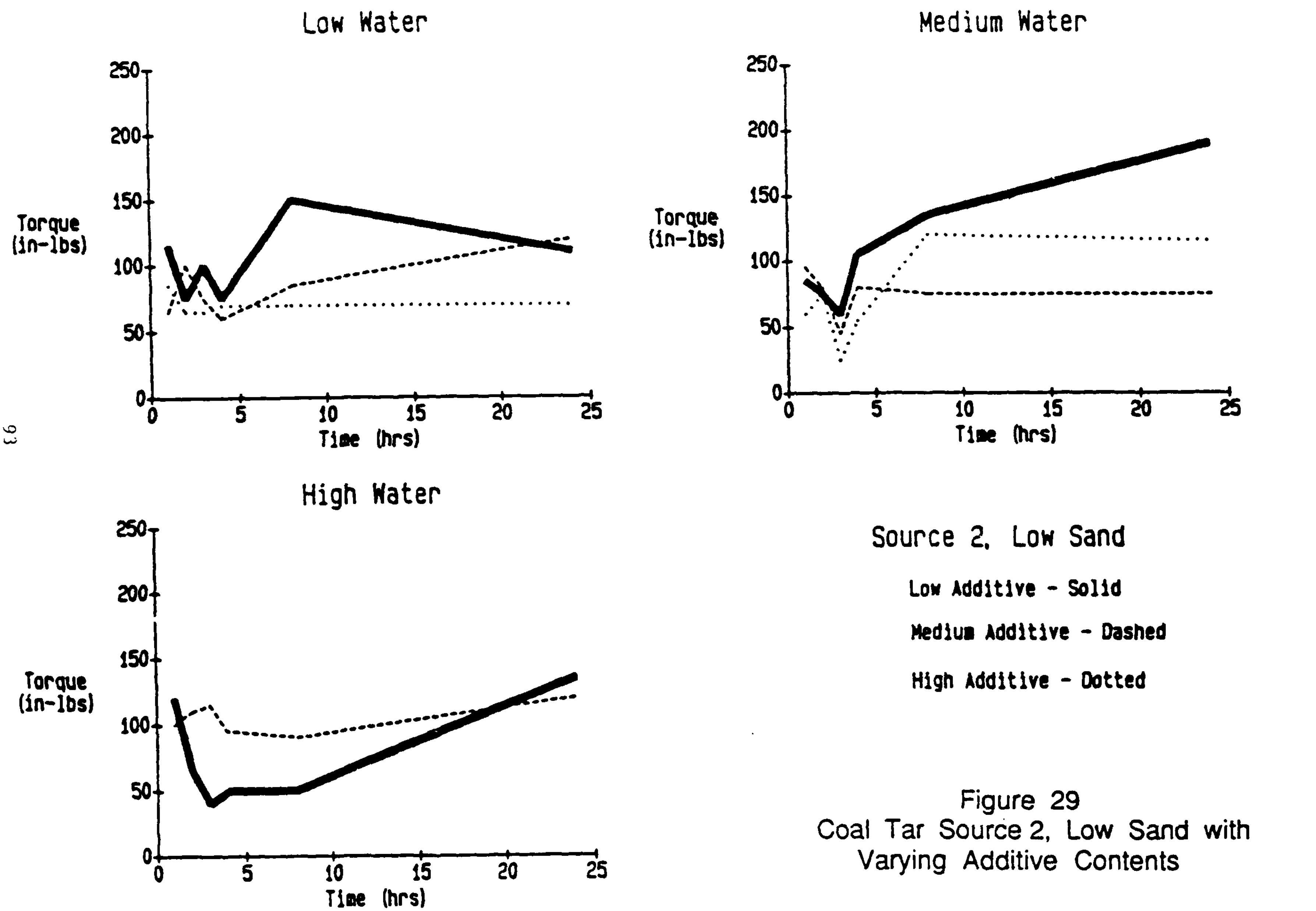


Figure 29
Coal Tar Source 2, Low Sand with Varying Additive Contents

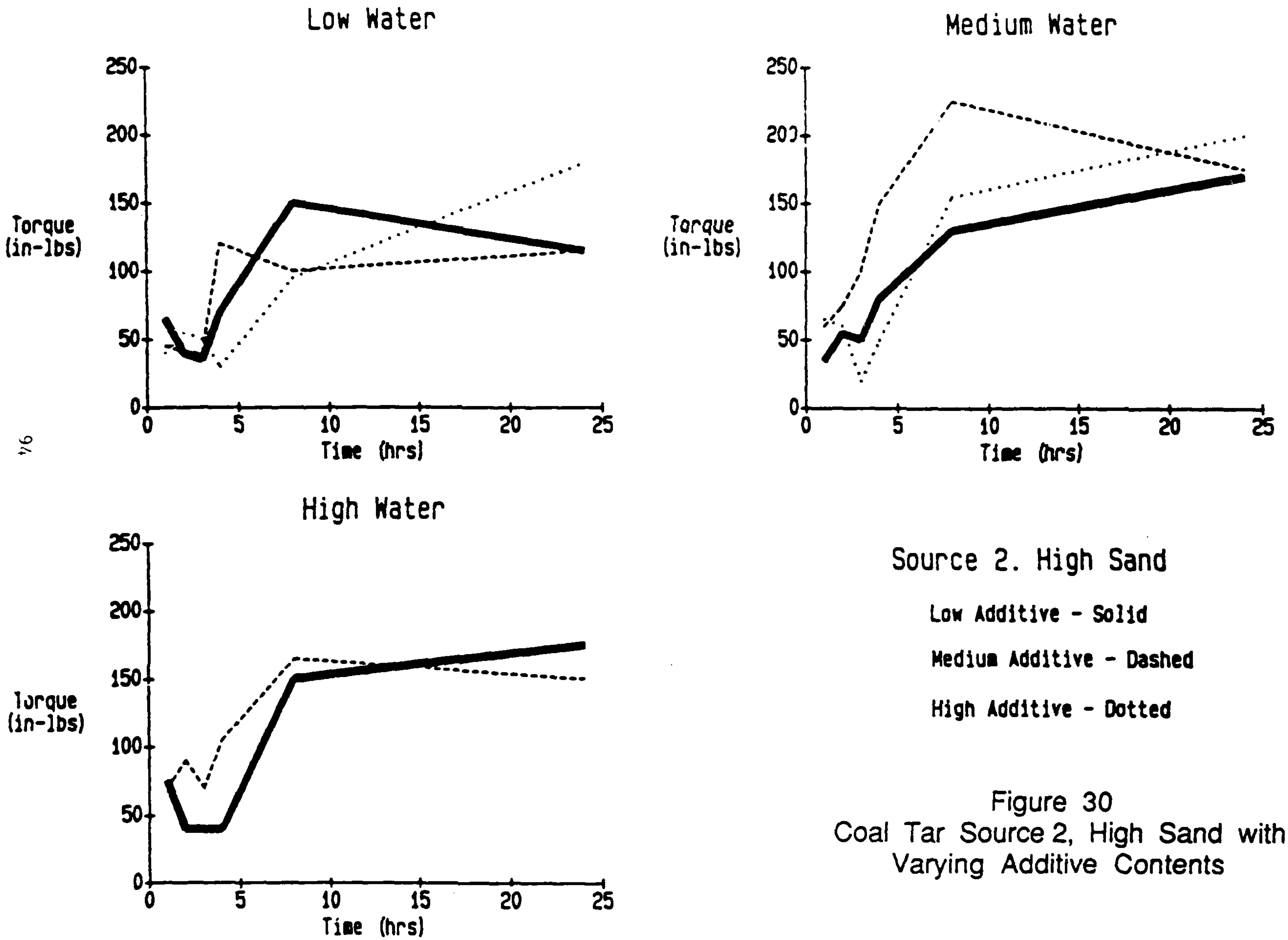


Figure 30
Coal Tar Source 2, High Sand with
Varying Additive Contents

Table 36 Influence of Increasing Sand Content on Torque Readings at 4 Hours of Cure Time for Phase 2 Testing

		4 HOUR CURE		
Source	Additive Content	Low Water Content	Med. Water Content	High Water Content
1	Low	DEC	INC	+
1	Med.	NC	INC	INC
1	High	+	+	+
2	Low	NC	DEC	NC
2	Med.	INC	INC	NC
2	High	DEC	NC	+
3	Low	INC	DEC	NC
3	Med.	+	DEC	DEC
3	High	NC	+	+
4	Low	NC	NC	NC
4	Med.	NC	INC	INC
4	High	+	NC	NC
6	Low	+	DEC	DEC
6	Med.	+	+	NC
6	High	+	INC	+

INC - addition of sand increased torque reading
DEC - addition of sand decreased torque reading
NC - addition of sand produced no change in the torque reading
+ - unable to make comparison due to inability to test material

Table 37 Influence of Increasing Sand Content on Torque Readings at 8 Hours of Cure Time for Phase 2 Testing

		8 HOUR CURE		
Source	Additive Content	Low Water Content	Med. Water Content	High Water Content
1	Low	DEC	INC	+
1	Med.	NC	INC	INC
1	High	+	+	+
2	Low	NC	DEC	INC
2	Med.	NC	INC	INC
2	High	INC	INC	+
3	Low	NC	NC	INC
3	Med.	+	NC	INC
3	High	NC	+	+
4	Low	NC	NC	NC
4	Med.	INC	DEC	INC
4	High	+	INC	INC
6	Low	+	INC	DEC
6	Med.	+	+	INC
6	High	+	INC	+

INC - addition of sand increased torque reading
DEC - addition of sand decreased torque reading
NC - addition of sand produced no change in the torque reading
\+ - unable to make comparison due to inability to test material

Table 38 Influence of Increasing Sand Content on Torque Readings at 24 Hours of Cure Time for Phase 2 Testing

		24 HOUR CURE		
Source	Additive Content	Low Water Content	Med. Water Content	High Water Content
1	Low	INC	INC	+
1	Med.	INC	INC	NC
1	High	+	+	+
2	Low	NC	DEC	INC
2	Med.	NC	INC	INC
2	High	NC	INC	+
3	Low	INC	NC	NC
3	Med.	+	NC	NC
3	High	NC	+	+
4	Low	NC	NC	NC
4	Med.	INC	DEC	NC
4	High	+	INC	DEC
6	Low	+	INC	INC
6	Med.	+	+	INC
6	High	+	INC	+

INC - addition of sand increased torque reading
DEC - addition of sand decreased torque reading
NC - addition of sand produced no change in the torque reading
+ - unable to make comparison due to inability to test material

CRACKING

Cracking test data and results of field observations are included in Appendix E.

Analyses of the test data are given in the following paragraphs.

Cyclic Freeze-Thaw Conditioning

Field Samples

Figures 31, and 32 illustrates relationships for crack severity verses time for laboratory conditioning of field section 9 with and without a topcoat. In addition to freeze-thaw conditioning, 140°F conditioning is also shown in this figure. In order to plot the results of these two methods of conditioning, freeze-thaw cycles had to be converted to days. The test takes two days per cycle. In these test the freeze-thaw conditioning was more severe than 140°F conditioning; and the freeze-thaw condition cycle was adopted for use in the remainder of the study.

Phase 1

Laboratory prepared freeze-thaw samples (4 inches by 4 inches) failed to develop cracking after five cycles. This lack of correlation between field prepared and lab prepared samples was probably due to the smaller sample dimension. The thermal stress and other volume change stress developed in the sample appear to be related to the surface area exposed to the freeze-thaw conditioning. Freeze-thaw analysis was discontinued in this phase of laboratory testing.

Phase 2

The freeze-thaw sample size was increased to 11-inches by 11-inches, in phase 2, cracking observed as before. The sections to follow will consider the influence of:

(1) Additive content
(2) Water content
(3) Sand content

on the cracking developed by freeze-thaw conditioning.

Additive: Information was compared for three additive contents while holding the water and sand contents constant. The additive contents were 4, 14.5, and 25 gal per 100 gal coal tar emulsion. Figures 33 through 36 show crack severity verses time for coal tar source 1 and 2, respectively.

Table 39 provides a summary of the influence of increasing additive content on crack severity after 10 cycles of freeze-thaw conditioning. Review of this table suggests that when the additive content is increased

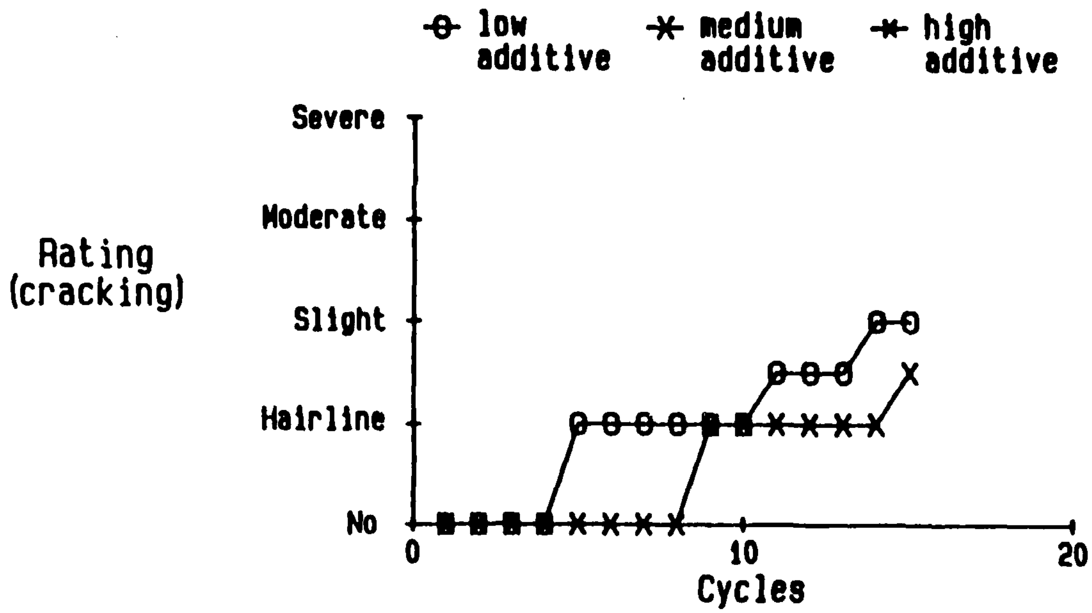


Figure 33 Cyclic Freeze-Thaw Conditioning
Source 1, Low Water, Low Sand

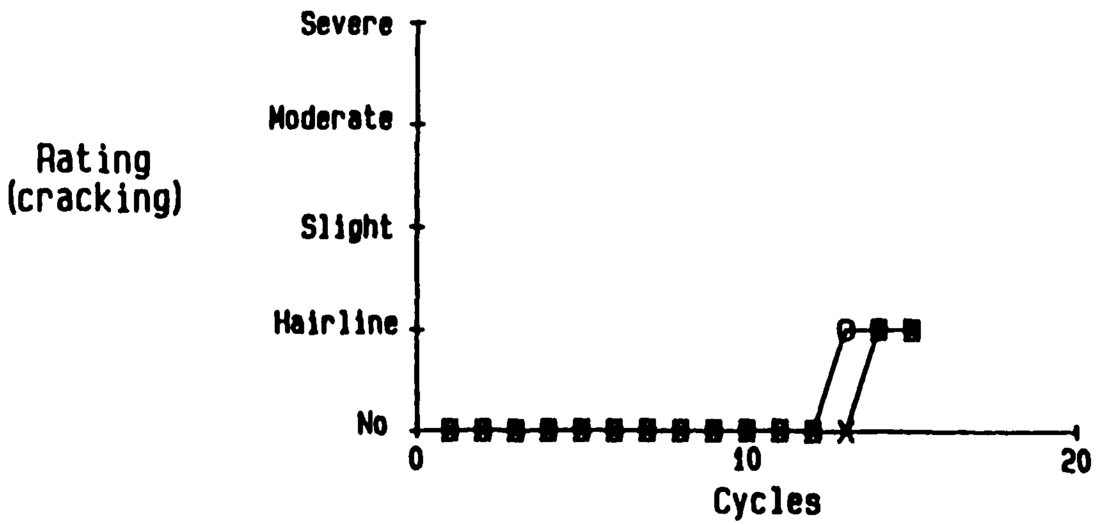


Figure 34 Cyclic Freeze-Thaw Conditioning
Source 1, Low Water, High Sand

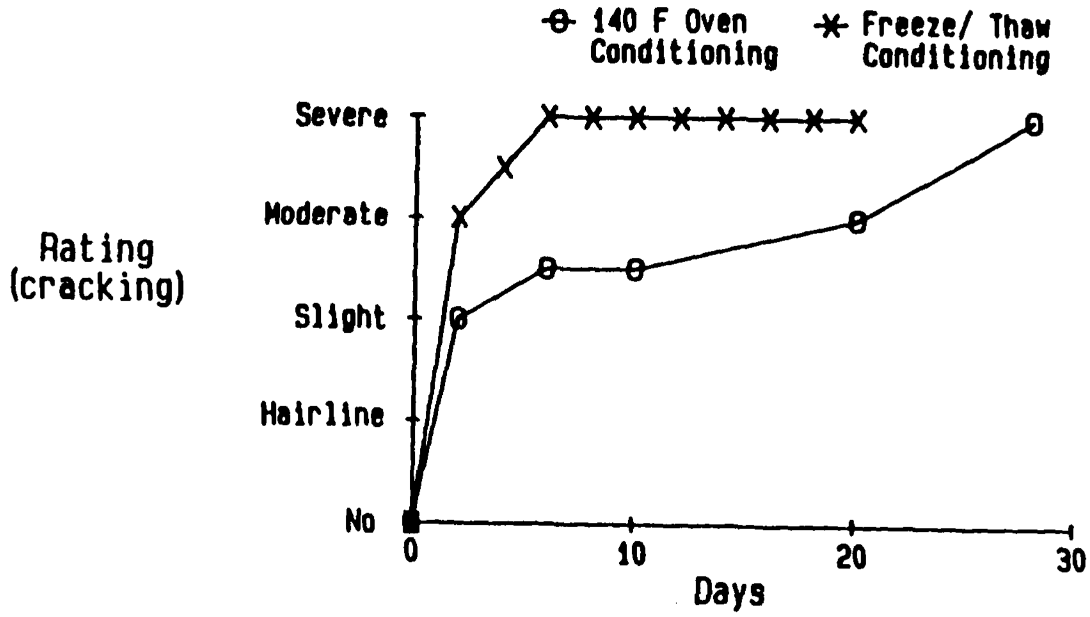


Figure 31 Lab Conditioning of Field Sample (Section 9) with Topcoat

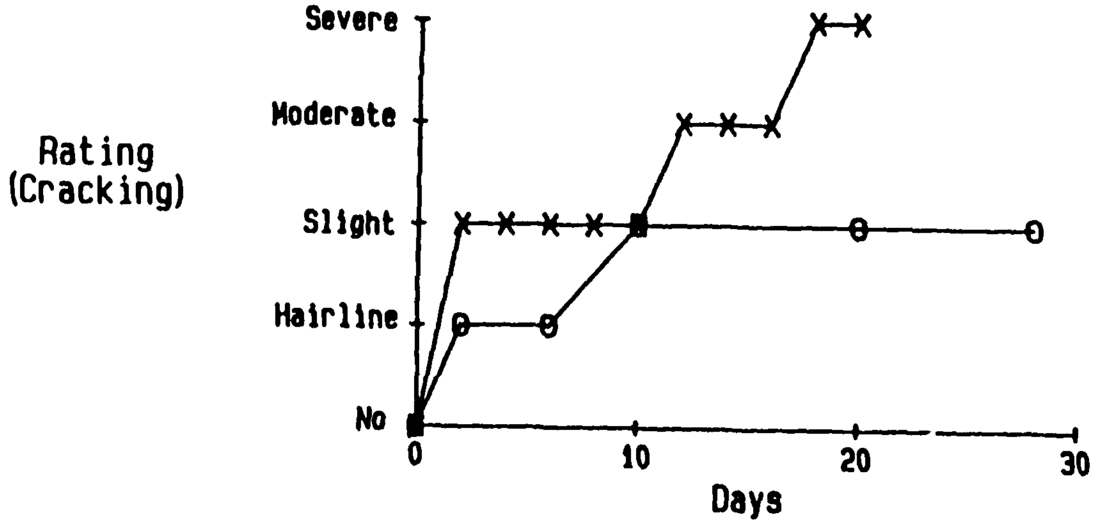


Figure 32 Lab Conditioning of Field Sample (Section 9) without Topcoat

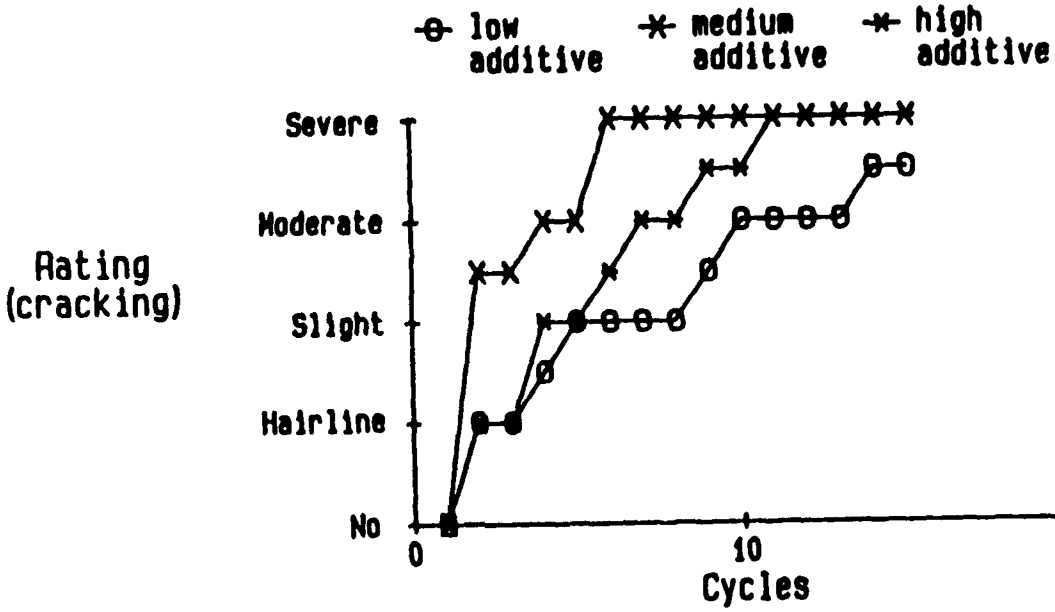


Figure 35 Cyclic Freeze-Thaw Conditioning Source 2, Low Water, Low Sand

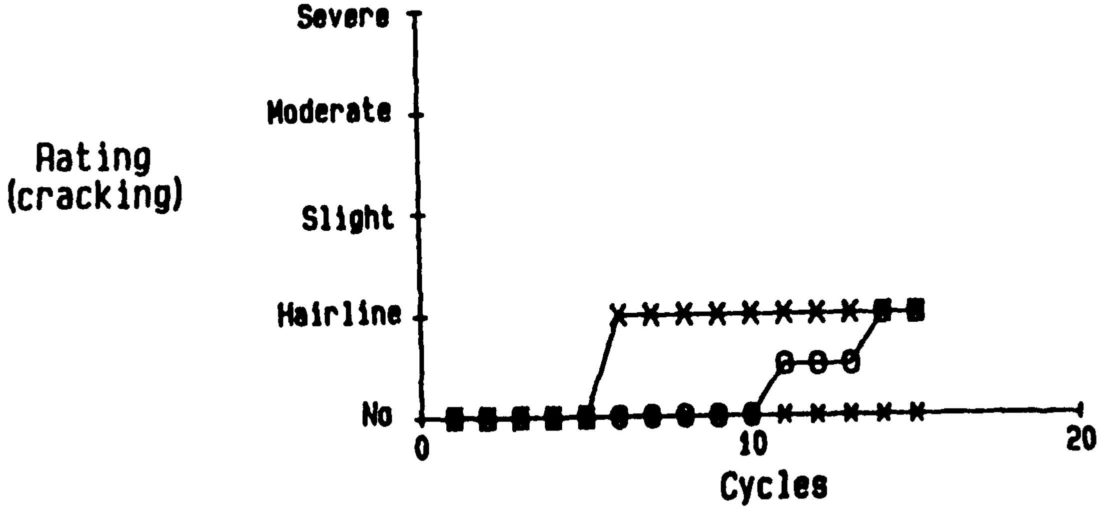


Figure 36 Cyclic Freeze-Thaw Conditioning Source 2, Low Water, High Sand

Table 39 Influence of Increasing Additive Content on Crack Severity Developed after 10 Cycles of Freeze-Thaw Conditioning

Source	Sand Content	Low Water Content	Med. Water Content	High Water Content
1	Low	NC*	DEC*	DEC*
1	High	NC*	INC*	+
2	Low	INC	INC	INC*
2	High	VAR	NC	INC*
3	Low	INC	INC*	INC*
3	High	INC*	INC*	INC*
4	Low	NC	NC	INC
4	High	NC*	NC	INC
6	Low	+	INC	INC
6	High	+	INC*	INC

INC - Addition of additive increased crack severity
DEC - Addition of additive decreased crack severity
VAR - Addition of additive varied crack severity
NC - Addition of additive produced no change in crack severity
* - Indicates trend is based on two levels of additive only
+ - Unable to make comparision due to inability to test material

Water Content
Low = 20 gal/100 gal CT
Medium = 55 gal/100 gal CT
High = 90 gal/100 gal CT

Sand Content
Low = 2 lbs/gal CT
High = 13 lbs/gal CT

at the high water content, the crack severity increases. This would indicate that the higher the total water content of the mix, the higher the crack severity.

Water: Relationships were developed for three water contents while holding the additive and sand contents constant. The water contents were 20, 55, and 90 gal/100 gal coal tar emulsion. Figures 37 through 40 show crack severity verses time for coal tar source 2 and 4, respectively.

Table 40 provides a summary of the influence of increasing water content on crack severity after 10 cycles of freeze-thaw conditioning. After review of this table it is evident there might be a trend to indicate that crack severity increases with an increase in water content.

Sand: Freeze-thaw data was compared for two sand contents. These sand contents were 2 and 13 lbs per gal coal tar emulsion. In these comparisons, the water and additive contents were held constant. Figures 41 through 44 show typical crack severity verses time relationships for coal tar sources 3 and 6 with high and low sand contents, respectively. From these figures it appears that with an increase in sand content the crack severity decreases.

Table 41 provides a review of the influence of increasing sand content on crack severity at 10 cycles of freeze-thaw conditioning. From this table it is clear that an increase in sand content reduces crack severity.

Flexibility

Phase 1

The flexibility test was performed in both stages 2 and 3 (with and without sand, respectively) of the testing program in accordance with ASTM D 2939. Results, were variable, but there was a slight increase in flexibility with increase in sand content.

Phase 2

Due to the limited information gained from Phase 1 of the results, the flexibility test was not performed in this phase of testing.

Shrinkage

Phase 1

Laboratory prepared samples exhibited several problems. Mixtures with high water contents (low viscosities) flowed extensively after the mask used for application was removed. This made it impossible to determine and accurately measure the coating movement. Mixtures with high additive contents coagulated so application was next to impossible. Because of these problems, testing was discontinued for this phase of testing.

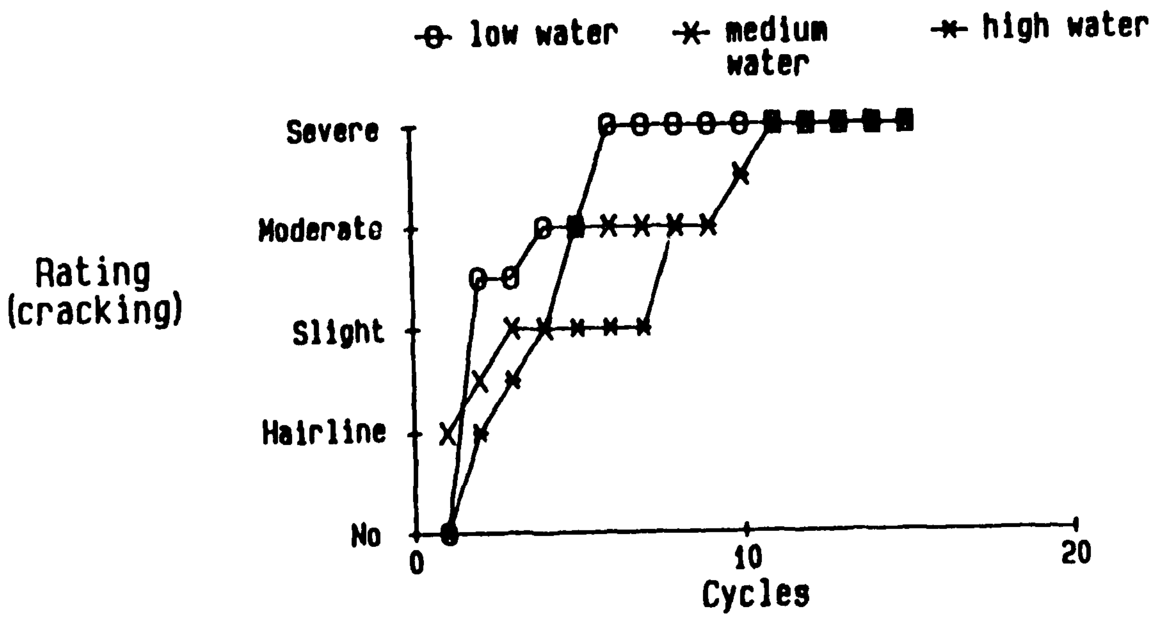


Figure 37 Cyclic Freeze-Thaw Conditioning, Source 2
Medium Additive, Low Sand

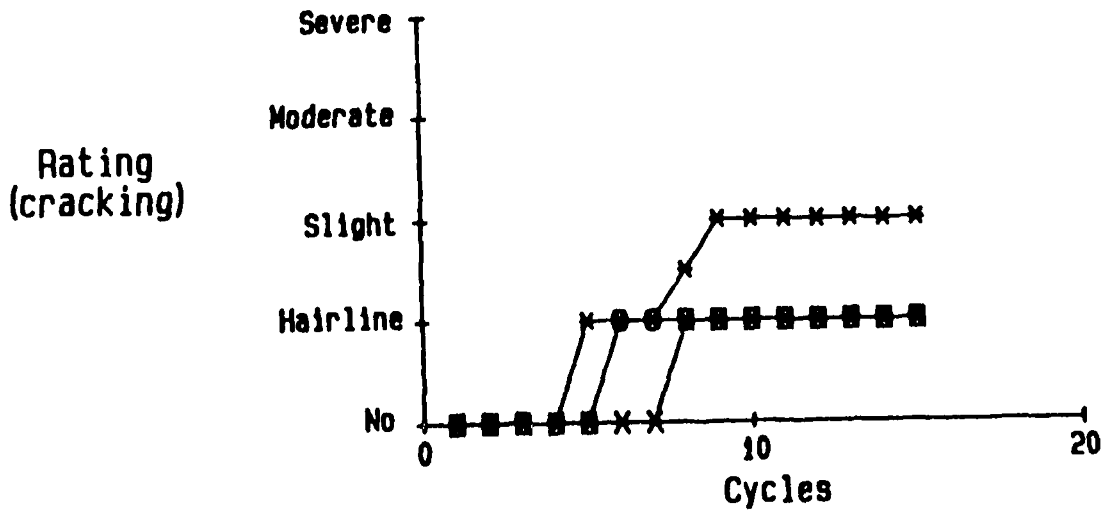


Figure 38 Cyclic Freeze-Thaw Conditioning, Source 2
Meduim Additive, High Sand

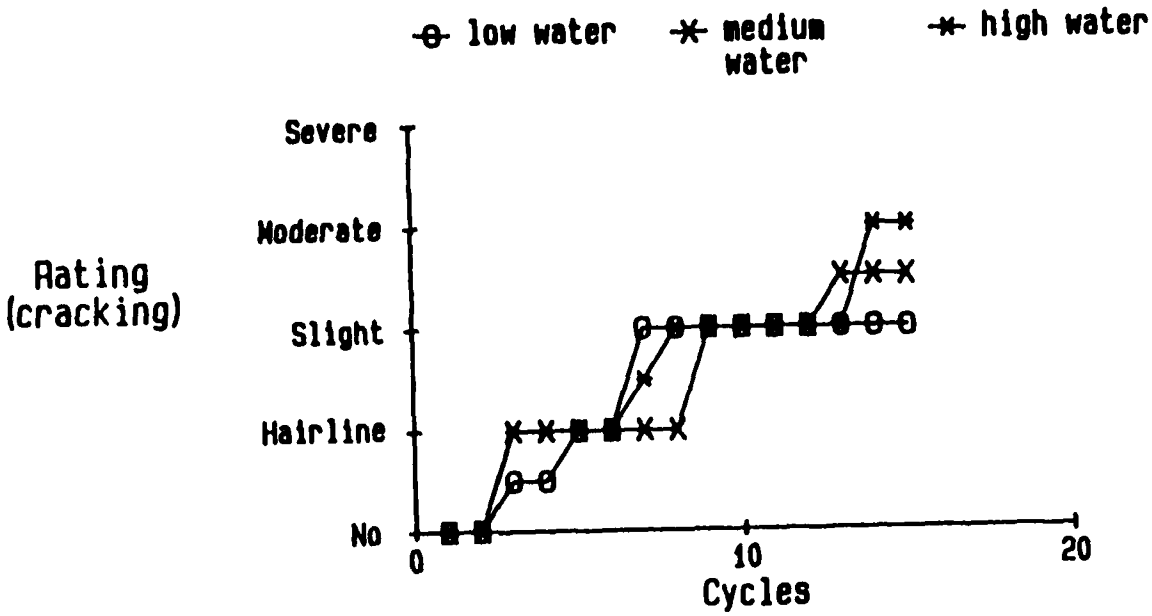


Figure 39 Cyclic Freeze-Thaw Conditioning, Source 4 Medium Additive, Low Sand

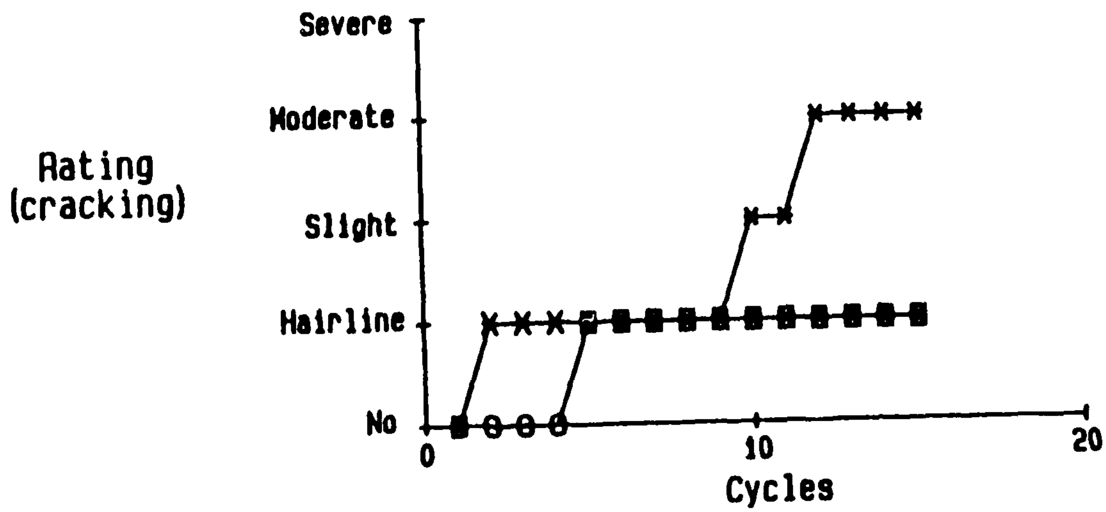


Figure 40 Cyclic Freeze-Thaw Conditioning, Source 4 Medium Additive, High Sand

Table 40 Influence of Increasing Water Content on Crack Severity Developed after 10 Cycles of Freeze-Thaw Conditioning

Source	Sand Content	Low Additive Content	Med. Additive Content	High Additive Content
1	Low	INC	INC	+
1	High	NC*	VAR	+
2	Low	VAR	NC	NC*
2	High	INC	INC	INC*
3	Low	NC	VAR	+
3	High	INC	NC*	+
4	Low	VAR	NC	INC
4	High	NC	INC	INC
6	Low	DEC*	INC*	+
6	High	NC*	+	+

INC - Addition of water increased crack severity
DEC - Addition of water decreased crack severity
VAR - Addition of water varied crack severity
NC - Addition of water produced no change in crack severity
* - Indicates trend is based on two levels of water only
+ - Unable to make comparision due to inability to test material

Additive Content
Low = 4 gal/100 gal CT
Medium = 14.5 gal/100 gal CT
High = 25 gal/100 gal CT

Sand Content
Low = 2 lbs/gal CT
High = 13 lbs/gal CT

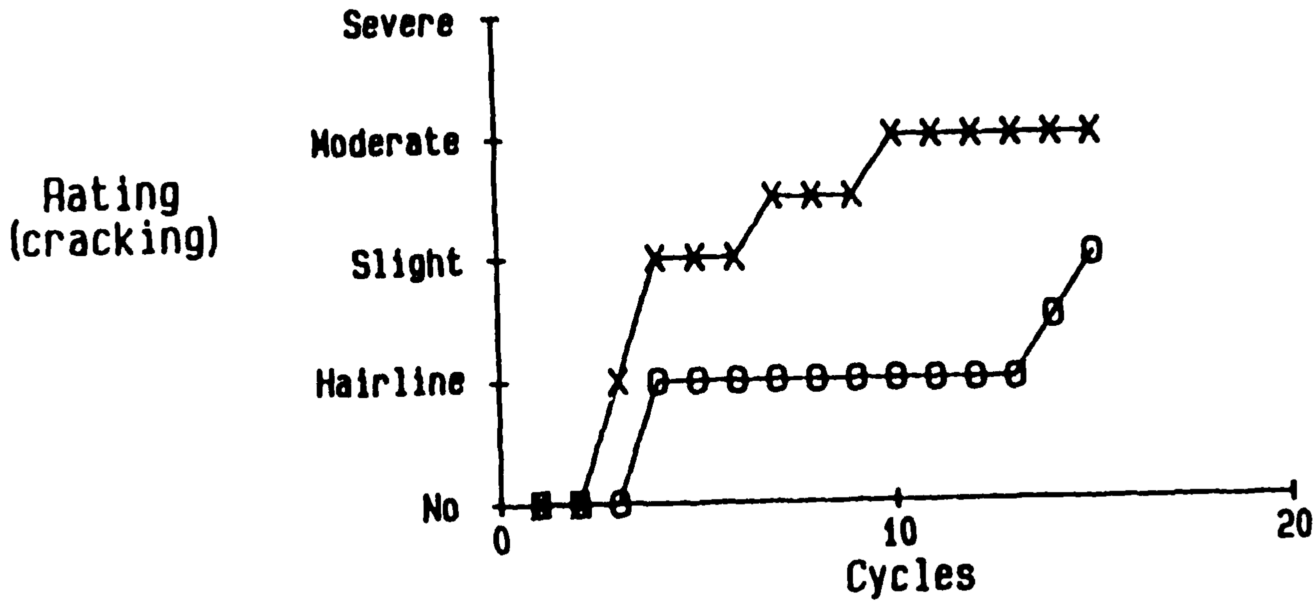


Figure 41 Cycliç Freeze-Thaw Condtioning, Source 3 Medium Water, Low Sand

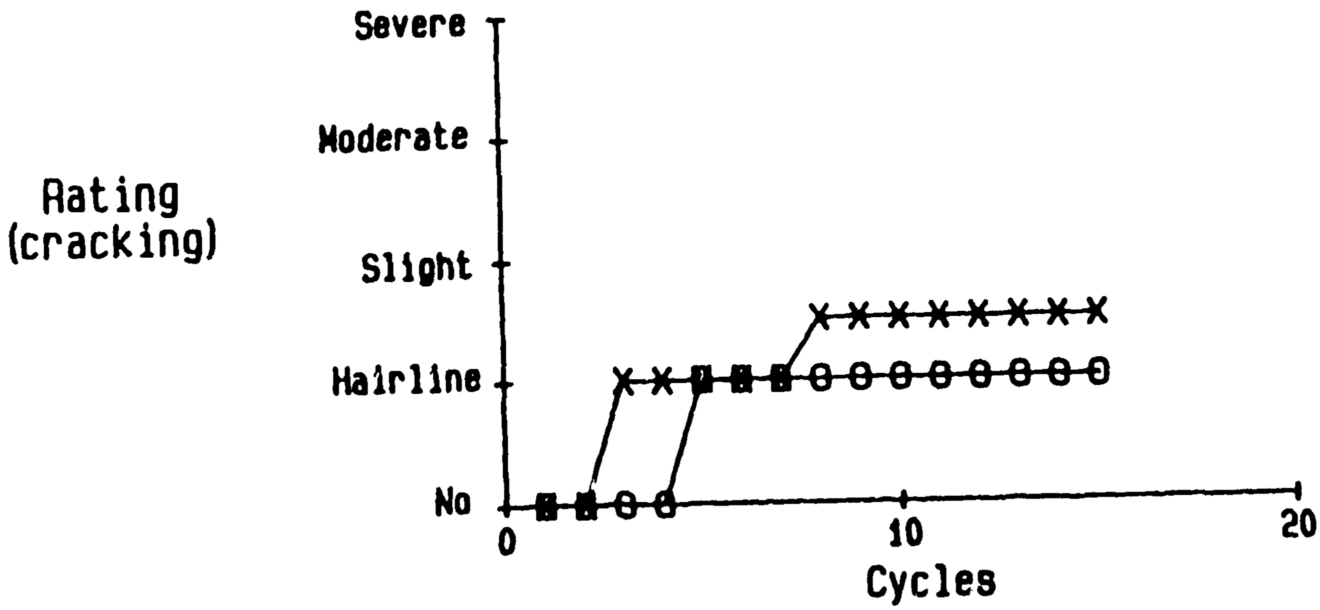


Figure 42 Cyclic Freeze-Thaw Conditioning, Source 3 Medium Water, High Sand

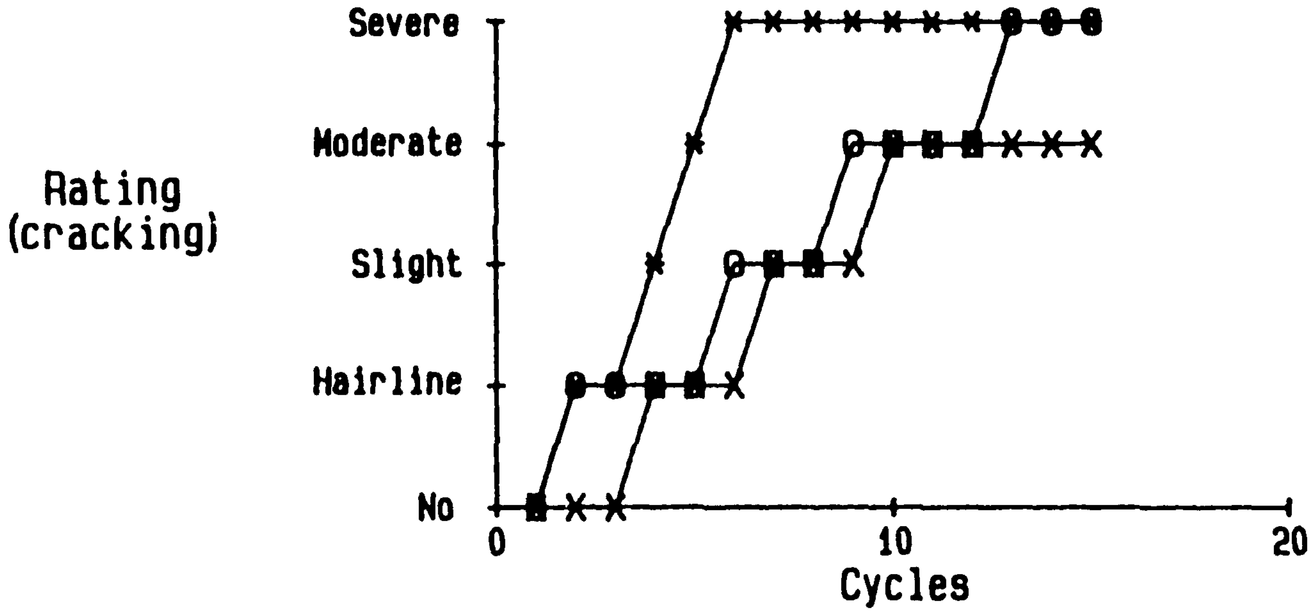


Figure 43 Cyclic Freeze-Thaw Conditioning, Source 6 Medium water, Low Sand

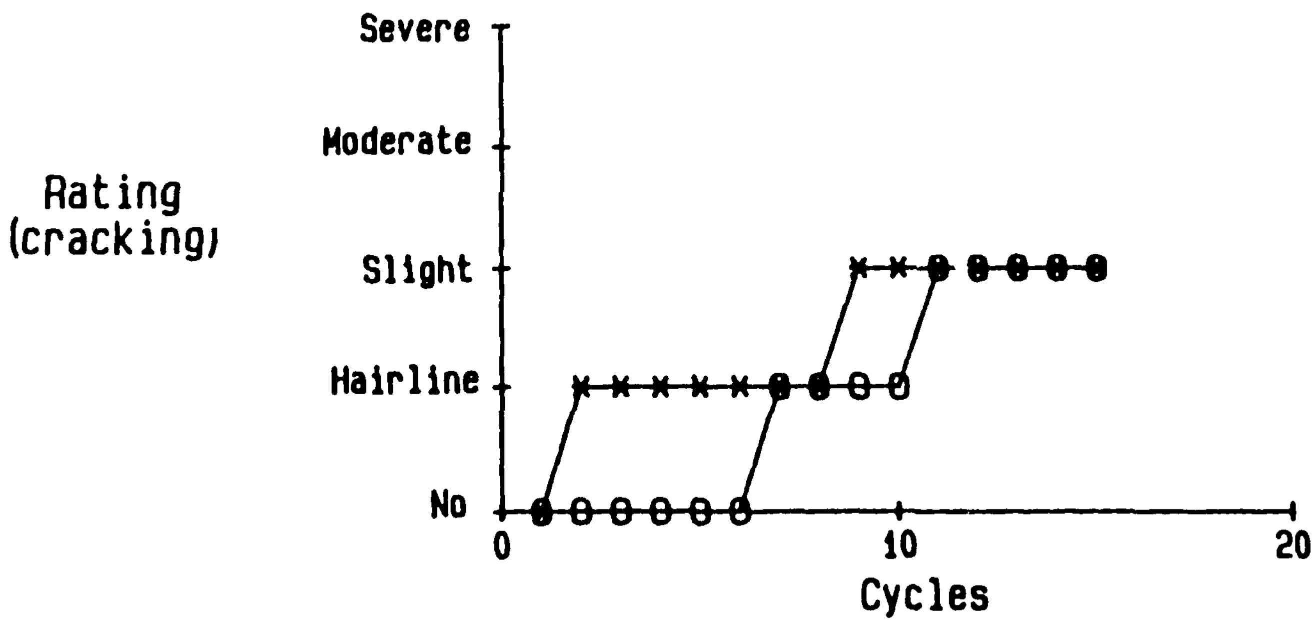


Figure 44 Cyclic Freeze-Thaw Conditioning, Source 6 Medium Water, High Sand

Table 41 Influence of Increasing Sand Content on Crack Severity Developed after 10 Cycles of Freeze-Thaw Conditioning

Source	Additive Content	Low Water Content	Med. Water Content	High Water Content
1	Low	DEC	DEC	+
1	Med.	DEC	NC	DEC
1	High	+	+	+
2	Low	DEC	DEC	DEC
2	Med.	DEC	DEC	DEC
2	High	DEC	DEC	+
3	Low	DEC	NC	NC
3	Med.	+	DEC	NC
3	High	DEC	+	+
4	Low	DEC	DEC	NC
4	Med.	DEC	DEC	NC
4	High	+	DEC	DEC
6	Low	+	DEC	DEC
6	Med.	+	+	NC
6	High	+	DEC	+

INC - Addition of sand increased crack severity
DEC - Addition of sand decreased crack severity
NC - Addition of sand produced no change in crack severity
\+ - Unable to make comparision due to inability to test material

Water Content
Low = 20 gal/100 gal CT
Medium = 55 gal/100 gal CT
High = 90 gal/100 gal CT

Additive Content
Low = 4 gal/100 gal CT
Medium = 14.5 gal/100 gal CT
High = 25 gal/100 gal CT

Phase 2

Due to the difficulties encountered in Phase 1, shrinkage testing was not performed in this phase of testing.

ADHESION

Adhesion test data are given in Appendix F.

Results of analyses of the data are given in the following paragraphs.

Phase 1

Evaluation of adhesion was not performed in Phase 1 of the laboratory testing program.

Phase 2

As previously mentioned, adhesion testing was performed using the cross hatch tape test (17). All samples, with very few exceptions, exhibited no peeling or coating removal (rating of 5A according to ASTM rating scale).

Sand was removed from several samples when the tape was pulled back. This was recorded as a "plus" sign with the adhesion rating. Sand removal occurred mainly on samples with high sand contents.

FUEL RESISTANCE

Fuel resistance test data are given in Appendix G.

Results of analyses of the data are given in the following paragraphs.

Phase 1

Fuel resistance of the coal tar sealers was measured using the kerosene resistance test. The results are measured on a pass/fail basis. The data for this test did not show any significant trends.

Phase 2

In Phase 2, fuel resistance was measured using the fuel drip followed by the wet track abrasion procedure developed by the Army Corps of Engineers.

The data reported includes the weight of coal tar sealer applied to the abrasion surface and the weight lost or gained during the test. If the weight lost during the test was greater than the weight of the material

applied to the abrasion surface, then the abrasion head had worn away the coal tar sealer. If the weight increased after the test then the fuel had penetrated the sealer.

ADDITIONAL RESULTS

The results of special tests performed to determine the influence of no additive and 16 pounds of sand per gallon of coal tar were conducted after the main experimental work had been completed. Table 42 contains the results for viscosity, flexibility, tile, and scuff resistance tests on mixes without sand. It can be seen that the samples with sand exhibited hairline cracking after performing the flexibility test, and medium and high sand content samples failed the tile test.

The results of the viscosity, settling and scuff tests are on emulsion mixes with 16 lb sand loadings given contained in Table 43. It can be seen that the increase in sand content does not greatly affect the viscosity or the 24 hour torque value of the mixtures.

Table 42 Results for Mixtures without Additive (Source 1)

Water	Sand	Visc. (poise)	Flex. Rat.	Tile (P/F)	Scuff Test Results Cure Time (hours) 3	4	24
					Torque (in.-lbs.)		
Med.	No	4.4	1*	N/A	-	-	-
Med.	Low	5.0	1*+	P	115	100	150**
Med.	Med.	6.7	0 +	F	80	75	150**
Med.	High	10.1	0 +	F	55	45	150**

* - Material released from panal
** - Maximum reading on torque wrench
\+ - Sample displayed hairline cracking
N/A - Not Applicable

Water

Medium = 55.0 gal/100 gal CT

Sand

No Sand
Low = 2 lbs/gal CT
Medium = 7 lbs/gal CT
High = 13 lbs/gal CT

Table 43 Results for Mixtures with 16 Pounds of Sand (Source 1)

Add.	Water	Sand (lbs)	Visc. (Poise)	Settl. final/ intial	Scuff Test Results Cure Time (hours) 4	8	24
					Torque (in-lbs)		
Med.	Low	13	135.0	MAX	145	135	180
Med.	Med.	13	58.0	MAX	110	150	200
Med.	High	13	17.3	MAX	85	75	170
Med.	Low	16	126.0	MAX	120	185	135
Med.	Med.	16	47.6	MAX	40	100	200
Med.	High	16	17.6	MAX	35	205	170

Max - Unable to rotate paddle with maximum weight

Additive

Medium = 14.5 gal/100 gal CT

Water

Low = 20.0 gal/100 gal CT
Medium = 55.0 gal/100 gal CT
High = 90.0 gal/100 gal CT

CHAPTER IV DETERMINING MIXTURE COMPOSITION

After review of Phase 1 and 2 of the laboratory test results the following tests were found to distinguish between mixture component changes:

(1) Viscosity (Brookfield)
(2) Scuff test
(3) Cyclic freeze-thaw test
(4) Adhesion

While the Tile test (fuel resistance) was not sensitive to mixture changes, it should be used as a pass/fail test to indicate fuel resistance.

The following tests were excluded from further consideration because they were not sensitive to mixture component changes or did not yield significant results:

(1) Settling
(2) Flexibility
(3) Shrinkage
(4) Fuel drip followed by the wet track abrasion procedure

As part of the analysis section, repeatability and desirable test limits will be considered for each of the test methods which were chosen after review of the laboratory test results.

REPEATABILITY

Upon completion of phase 2, a mini study was performed to determine the repeatability of the:

(1) Viscosity
(2) Scuff
(3) Cyclic freeze-thaw tests

The purpose of the study was to determine if the differences observed in the test results were actual material differences or were within test variations.

Mixture formulations for this study were chosen from Phase 2 results which had low, medium, and high viscosity and settling results, regardless of material source. This range of values was chosen to establish test variation for the widest range of test results possible. Three samples for each formulation were examined for each test and testing was performed as previously described. It should be noted that the following results

reflect single operator, within laboratory, test variations. Multi-laboratory testing would be expected to produce higher variations in the test results.

Viscosity Testing

Results of the viscosity study are given in two tables, Table 44 and 45, for total liquids in the mixture; and in Tables 46 and 47 for the composite mixture.

Figure 45 shows the standard deviation increasing with an increase in magnitude of the viscosity, this would indicate something other than a linear relationship. Therefore in order to define test variability, one must consider a uniform parameter across the viscosity ranges. In this case the coefficient of variation was chosen to define test variability. The coefficient of variation is used to express the standard deviation as a percentage of the average or:

$$CV = s / x$$

where:

CV = coefficient of variation

s = standard deviation

x = average

The average coefficient of variation for the total liquids and composite mix were 3.7 and 8.0, respectively. With these values, the standard deviation for any viscosity range can be found. This can be illustrated through an example.

First consider a total liquids mixture with an average viscosity of 25.5 poise (sample 30, Table 44), and a coefficient of variation (CV) of 3.7. It should be noted that because the CV was developed from an average of three viscosity values, the average of three values must be used to find the standard deviation. With the information given, the standard deviation is calculated as 0.94 poise. This can be compared to the actual standard deviation of 1.21 poise in Table 41. Now consider an average viscosity of 89.0 poise (sample 73, Table 45) and a CV of 3.7. With the information given, the standard deviation is calculated as 3.29 as compared to the actual standard deviation of 3.89. This procedure can be used to calculate standard deviation can be for a range of average viscosity values.

Now consider a composite mixture with an average viscosity of 4.53 (sample 64, Table 47) and a CV of 8.0. The standard deviation can be calculated as 0.36 poise as compared to the actual standard deviation of 0.51 poise. As an extreme, consider an average viscosity of 62.73 (sample 30, Table 46) and a CV of 8.0. The calculated standard deviation is 5.02 poise, as compared to the actual value of 4.70 poise. It is important to note that if the CV is developed from an average of three viscosities then an average of three viscosities must be used to find the standard deviation.

Table 44 Single Operator-within Laboratory Test Variation
Physical Properties of Coal Tar Emulsion, Additive, and Water

Sample Number	Additive	Water	Viscosity (Poise)	Settling final/ intial
1	Medium	Medium	7.9	6.8
			7.7	10.2
			7.9	7.5
	Average		7.83	8.17
	Standard Deviation		0.12	1.80
	Coef. of Variation		1.47	21.98
30	Medium	Medium	24.4	5.9
			26.8	2.8
			25.4	2.8
	Average		25.53	3.83
	Standard Deviation		1.21	1.79
	Coef. of Variation		4.72	46.69
46	Medium	Low	47.8	1.0
			47.0	1.9
			46.8	2.4
	Average		47.20	1.77
	Standard Deviation		0.53	0.71
	Coef. of Variation		1.12	40.16

Table 45 Single Operator-within Laboratory Test Variation
Physical Properties of Coal Tar Emulsion, Additive, and Water

Sample Number	Additive	Water	Viscosity (Poise)	Settling final/ intial
62	Medium	Medium	8.5	8.0
			8.7	15.0
			8.8	13.6
	Average		8.67	12.20
	Standard Deviation		0.15	3.70
	Coef. of Variation		1.76	30.36
73	Medium	Medium	84.6	1.2
			90.4	1.3
			92.0	1.4
	Average		89.00	1.30
	Standard Deviation		3.89	0.10
	Coef. of Variation		4.37	7.69
84	Medium	High	3.3	10.2
			3.4	*
			3.6	*
	Average		3.43	10.20
	Standard Deviation		0.15	
	Coef. of Variation		4.45	

* - Unable to test

Table 46 Single Operator-within Laboratory Test Variation Physical Properties of Coal Tar Emulsion, Additive, Water, and Sand

Sample Number	Additive	Water	Sand	Viscosity (Poise)	Settling final/ initial
3	Medium	Medium	Low	7.2	58.1
				7.2	27.3
				7.3	26.8
	Average			7.23	37.40
	Standard Deviation			0.07	17.93
	Coef. of Variation			0.97	47.94
30	Medium	Medium	High	67.4	*
				62.8	*
				58.0	*
	Average			62.73	
	Standard Deviation			4.70	
	Coef. of Variation			7.49	
46	Medium	Low	Low	55.4	2.4
				59.0	*
				54.0	*
	Average			56.13	2.40
	Standard Deviation			2.58	
	Coef. of Variation			4.60	

Table 47 Single Operator-within Laboratory Test Variation Physical Properties of Coal Tar Emulsion, Additive, Water, and Sand

Sample Number	Additive	Water	Sand	Viscosity (Poise)	Settling final/initial
62	Medium	Medium	High	11.0	*
				13.1	*
				12.1	*
	Average			12.07	
	Standard Deviation			1.05	
	Coef. of Variation			8.70	
73	Medium	Medium	High	93.4	*
				84.4	*
				83.0	*
	Average			86.93	
	Standard Deviation			5.64	
	Coef. of Variation			6.49	
84	Medium	High	High	4.1	*
				4.4	*
				5.1	*
	Average			4.53	
	Standard Deviation			0.51	
	Coef. of Variation			11.32	

* Unable to test

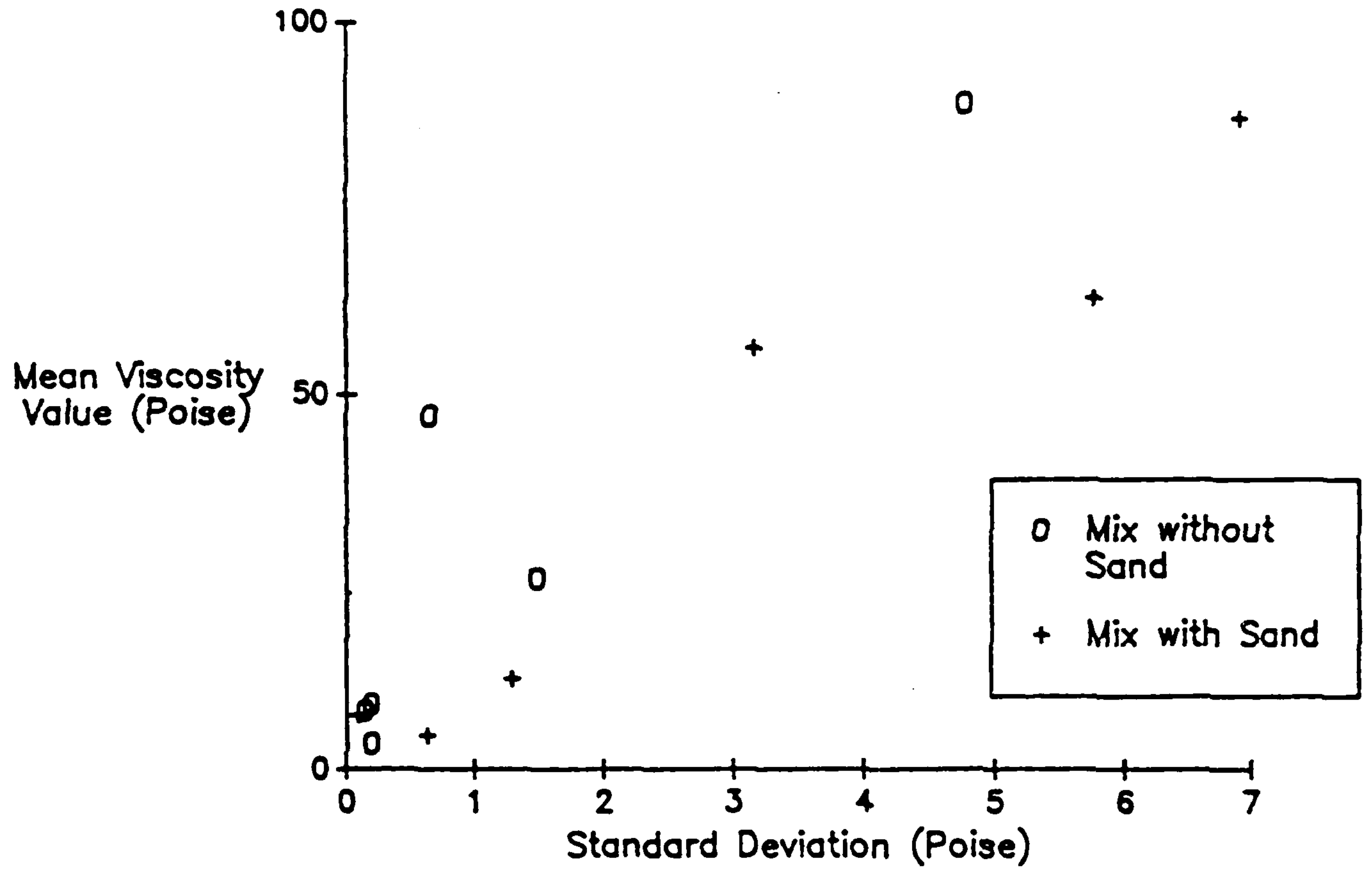


Figure 45: Mean Viscosity Versus Standard Deviation for Single Operator, within Laboratory Variation Study

Scuff Testing

Table 48 and 49 provides the results for repeatability of the scuff test. It can be seen that the standard deviations, at each cure time, are similar and fit a normal distribution. This would indicate a linear relationship. Therefore an average standard deviation was developed from the average variance (standard deviation squared) at each cure time. The average standard deviations are 13.02, 13.33, and 12.91 for the 4, 8 and 24 hour cure times respectively.

The F-test can be used to see if the variances are statically similar for the 4, 8, and 24 hour cure time. In this test the ratio of variances is calculated as follows:

$$\text{F-value} = s^2{}_1 / s^2{}_2$$

where:

$s^2{}_1$ = largest of two variances being evaluated

$s^2{}_2$ = variance of other cure time

Once the F-value is calculated, it is compared to a table value, which can be found in any standard statistics book. In this case, at a 95 percent confidence level (5 percent risk), the table F-value was found to be 2.26. The calculated values of 1.07, 1.05, and 1.02 are all smaller then the table value. The conclusion drawn from this comparison was that variances and standard deviations for the three cure times are statistically similar.

Since the average standard deviations for each cure time were found to be similar, an overall average standard deviation for the scuff test can be developed. Once again this was accomplished using the average variance for each cure time. The overall average standard deviation for the scuff test was found to be 13.09 in-lbs.

Cyclic Freeze-Thaw Conditioning

Tables 50 and 51 contain the results for the analysis of the test variation for the cyclic freeze-thaw test. This table shows crack severity through 15 cycles of freeze-thaw conditioning for three samples each of six formulations. It can be seen from this table that the standard deviation is not a function of the magnitude of the crack severity. Since this is the case, an average standard deviation can be used for the test. This was accomplished by calculating the square root of the average variances. Average variances for each of the six formulations at 1, 5, 10, and 15 freeze-thaw cycles were used in selecting a recommended value.

In performing the F-test, the ratio of the highest (0.33) to the lowest (0.24) variance was calculated and found to be 1.38 and a table F-value was found to be 2.26. This would indicate that there is statistically no difference in the variances at 1, 5, 10, and 15 freeze-thaw cycles. Therefore an average standard deviation of 0.29 can be found by taking the average of the square roots of the variances from the representative data base.

Table 48 Single Operator-within Laboratory Test Variation
Scuff Test Results

				Cure Time (hours)		
				4	8	24
Sample Number	Additive	Water	Sand	Torque (in-lbs)		
3	Medium	Medium	Low	100	130	120
				85	125	125
				75	140	12[illegible]
	Average			86.7	131.7	123.3
	Standard Deviation			12.58	7.64	2.89
	Coef. of Variation			14.52	5.80	2.34
30	Medium	Medium	High	45	190	180
				60	150	210
				70	150	190
	Average			58.3	163.3	193.3
	Standard Deviation			12.58	23.09	15.28
	Coef. of Variation			21.57	14.14	7.90
46	Medium	Low	Low	75	155	170
				80	160	180
				75	150	185
	Average			76.7	155.0	178.3
	Standard Deviation			2.89	5.00	7.64
	Coef. of Variation			3.77	3.23	4.28

Table 49 Single Operator-within Laboratory Test Variation Scuff Test Results

Sample Number	Additive	Water	Sand	Cure Time (hours) 4	8	24
				Torque (in-lbs)		
62	Medium	Medium	High	160	155	155
				130	175	150
				125	145	150
	Average			138.3	158.3	151.7
	Standard Deviation			18.93	15.28	2.89
	Coef. of Variation			13.68	9.65	1.90
73	Medium	Medium	High	45	175	145
				30	150	120
				60	175	150
	Average			45.0	166.7	138.3
	Standard Deviation			15.00	14.43	16.07
	Coef. of Variation			33.33	8.66	11.62
84	Medium	High	High	80	150	150
				65	150	160
				60	155	190
	Average			68.3	151.7	166.7
	Standard Deviation			10.41	2.89	20.82
	Coef. of Variation			15.23	1.90	12.49

Table 50 Single Operator-within Laboratory Test Variation for Cyclic Freeze-Thaw Conditioning

Sample Number		Freeze Thaw Cycles 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3																
	A	0	1	1	1	2	2	2	2	2	2	3	3	4	4	4
	B	0	1	1	1	2	2	2	2	2	2	3	3	4	4	4
	C	1	1	1	1	2	2	2	2	2	2	3	3	4	4	4
Average		0.3	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0	4.0	4.0	4.0
Std. Dev.		0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30																
	A	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2
	B	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2
	C	0	0	1	1	1	1	1	1	2	2	2	2	2	2	2
Average		0.0	0.0	0.3	1.0	1.0	1.0	1.0	1.0	1.3	2.0	2.0	2.0	2.0	2.0	2.0
Std. Dev.		0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
46																
	A	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	B	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2
	C	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2
Average		0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.7	1.0	1.3	1.3	1.3	1.7	1.7	1.7
Std. Dev.		0.0	0.0	0.0	0.6	0.6	0.6	0.6	0.6	0.0	0.6	0.6	0.6	0.6	0.6	0.6
62																
	A	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2
	B	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2
	C	0	0	0	1	1	1	1	1	1	1	1	2	2	2	2
Average		0.0	0.0	0.0	0.3	0.3	1.0	1.0	1.0	1.0	1.0	1.0	1.3	1.7	1.7	2.0
Std. Dev.		0.0	0.0	0.0	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6	0.6	0.0
73																
	A	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
	B	0	0	0	0	1	1	1	1	1	1	1	1	2	2	2
	C	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Average		0.0	0.0	0.0	0.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3	1.3	1.3
Std. Dev.		0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6	0.6

Table 51 Single Operator-within Laboratory Test Variation for Cyclic Freeze-Thaw Conditioning

Sample Number		Freeze Thaw Cycles														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
84																
	A	0	0	1	1	1	1	1	2	2	2	2	2	3	3	3
	B	0	0	1	1	1	1	1	2	2	2	2	2	3	3	3
	C	0	1	1	1	1	2	2	2	2	2	2	3	3	3	3
Average		0.0	0.3	1.0	1.0	1.0	1.3	1.3	2.0	2.0	2.0	2.0	2.3	3.0	3.0	3.0
Std. Dev.		0.0	0.6	0.0	0.0	0.0	0.6	0.6	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0

DETERMINATION DESIRABLE TEST LIMITS

Limits were established to produce desirable properties of the sealers for each test method based on the review of the results and extensive visual observation. These limits are given in Table 52, and discussed below.

Workability

Viscosity: Desirable viscosity limits were established by evaluation of laboratory testing, extensive visual observation of ease of mixing, consistency of the material, and the ability of a technician to prepare samples. Materials with viscosities of less than 10 poises were too fluid while trying to prepare samples; sands rarely stayed in suspension. Materials of this low of a viscosity would tend to "run" off of a pavement if it was used in the field. Viscosities of greater than 90 poises were accompanied by one or more of the following problems:

1. Obvious coagulation
2. Lumping
3. Inability to spread material
4. A thick layer at the bottom of the container indicating either the additive or sand thickening or settling out. These type of material problems cause uneven surface texture if squeegied; spray nozzles would definitely be clogged.

Scuff Resistance

Scuff test: Torque readings below 50 inch-pounds were indicative of material being pushed in front of the rubber abrasion head. Values of 80 inch-pounds or greater at 4 hours with a reduction in values at 8 hours was also an indication that the material was moving on the shingle. The high initial readings were the result of testing the shingle and not the seal coat; as the material set (8 hours) the test began to evaluate the seal coat instead of the shingle.

Torque readings between 50 and 100 inch-pounds were equated with the material shearing under the abrasion head. Some of the seal coat remained adhered to the shingle, but the surface of the seal coat tended to push in front of the abrasion head.

Based on these observations, 8 and 24-hour limits were set at:

1. A torque of a minimum of 100 inch-pounds at 8 hours.
2. A torque greater than the 8 hour reading at 24 hours.

The limit on the 24 hour reading insures that the 8 hour reading was actually measuring the seal coat and not the shingle.

Table 52 Proposed Test Procedures and Test Criteria

Step	Test Method	Performance Item	Criterion
1.	Brookfield Viscosity @ 77°F	Incompatibility between additive and coal tar	Viscosity between 10 and 90 poises CV = 3.7%
2.	Brookfield Viscosity @ 77°F	Workability of mix	Viscosity between 10 and 90 poises CV = 8.0%
3.	Scuff Resistance	Rate of set	8 hour torque $\geq$ 100 in-lbs
		Final Scuff resistance	24-hour torque > 8-hour torque Std Dev = 15 in-lbs
4.	Cyclic Freeze-Thaw Conditioning	Cracking	Rating $\leq$ 1 @ 5 cycles Rating $\leq$ 3 @ 10 cycles Std Dev = 0.29
5.	Tape Test	Adhesion	Rating = 5A No sand loss
6.	Tile Test	Fuel Resistance	Passes

Cracking

Cyclic freeze-thaw conditioning: Based upon a comparison of field cracking of test sections to freeze-thaw cracking of laboratory samples, rating limits were chosen as follows:

1.1 or less at the end of 5 cycles.
2.3 or less at the end of 10 cycles.

The relationship that was used to select a rating of 1 or less at 5 cycles and 3 or less at 10 cycles is shown in Figure 46. This figure shows laboratory cracking at 10 cycles plotted versus laboratory cracking at 5 cycles, with the symbols indicating the results of the field crack rating at 12 months, for each sample. These limits are based on field evaluation to date, and have produced a crack rating of 1 or less after one year in the field. Comparisons of 11 test section comprising a wide range of coal tar sources, additives, and sand gradations and shapes were the basis for the above ratings.

Peeling or Debonding

Adhesion: Most products tested indicated no peeling; however, most samples at the higher sand contents indicated a loss of sand retention. Therefore, limits were set as a rating of 5A with no sand being retained on the tape.

Fuel Resistance (Tile) Test

The tile test was not run in phase 2 of the laboratory study; however, it was believed that most formulations should pass this test, as determined in the phase 1 experiment.

DETERMINING MIXTURE COMPOSITION

A major objective of the laboratory program was to develop a method for determining optimum mixture composition for any given combination of coal tar emulsion, water, additive and sand, along with appropriate test criteria. The specific tests to be considered in mix design were determined in the laboratory study. As indicated earlier these tests included Brookfield viscosity measurements to detect incompatibilities between the coal tar and the latex additive, and to determine workability of the mix after adding sand. The scuff test was adopted to measure rate of set and scuff resistance. Other tests were adopted to measure resistance to cracking, adhesion loss and fuel resistance.

Criteria, or test limits, for viscosity were established from mix formulations that did not exhibit incompatibilities between the coal tar and the latex additives. Scuff test limits were based on an evaluation of the relationship between cure time and torque resistance measurements observed for various formulations, with consideration being given to the rate of curing observed in field applications. Criteria for freeze-thaw conditioning were selected based on comparing observations in the first

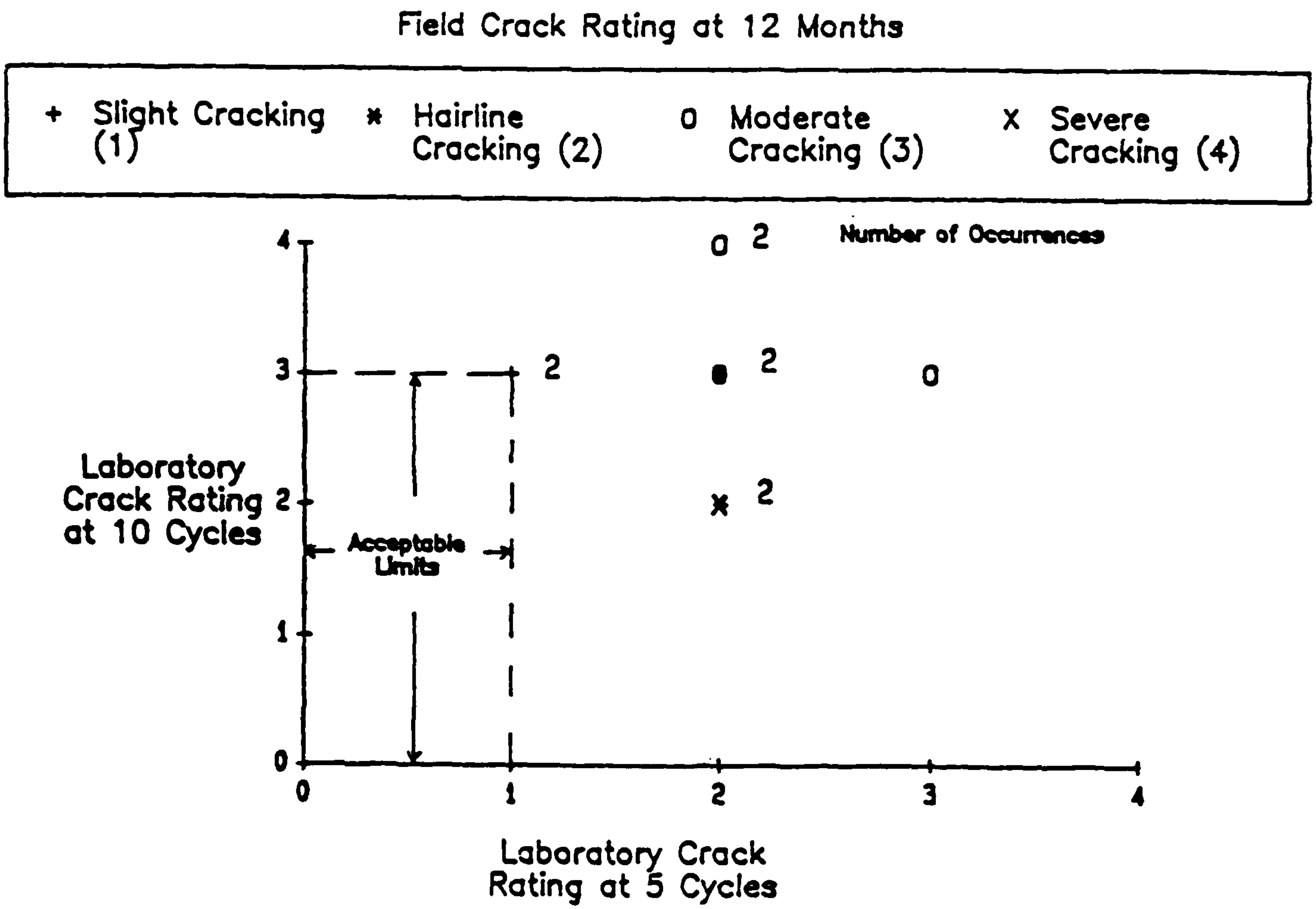


Figure 46: Relationship Between Laboratory Freeze-Thaw Cracking and Field Test Section Cracking

field test sections to the laboratory study results. Conservative readings were selected as criteria for the tape adhesion and tile fuel resistance tests.

Tentative test criteria for the final selection of test procedure are given in Table 52. Also included in Table 52 are suggested limits for single operator within test variability for the tests. Three samples for each formulation checked were tested to determine repeatability, and the results expressed as standard deviation or coefficient of variation.

MIX DESIGN PROCESS

The procedure adopted to determine optimum acceptable quantities of coal tar emulsion, water, latex, and sand makes use of a process in which trial batches with a range of formulations are prepared, then subjected to a sequence of six tests designed to eliminate the formulations not meeting test criteria. Unacceptable formulations are eliminated from further consideration.

Figure 47 outlines the process of checking a particular mix using the six steps in the process. Table 52 summarizes the test procedures, the associated mixture properties, and proposed criteria for each test procedure.

Steps in the Mix Design Process

There are six steps in the proposed mix design process as indicated in Figure 47. These six steps are applied to a range of materials and material quantities, emulsion, water, latex and sand, that are expected to bracket one or more acceptable mixes. It may be necessary to repeat step one in the process to find a range for any given combination of emulsion, latex and water. Once a range is established for these materials, the liquid phase of the sealer, the remaining 5 steps will lead to a selection of a final mix formulation having the desired properties.

Step 1: Perform the Brookfield viscosity test on each trial batch formulation of the liquid phase without sand: coal tar emulsion, latex additive, and water. Determine formulations that have the widest ranges for the quantities of latex and additive that meet the viscosity criteria given in Table 52.

Step 1 is designed to eliminate formulations that might have incompatible quantities of latex rubber and coal tar emulsion, that might flocculate, that have viscosities too low to suspend sand, or that would produce and unacceptable coating. Visual observations of these conditions are helpful in determining acceptable formulations within the range of viscosity values given as test criteria.

Step 2 Brookfield viscosities are next determined on acceptable trial formulations from step 1. The purpose is to identify any new incompatibilities created by the introduction of sand, to insure that the composite material will not run off the pavement nor clog spray nozzles.

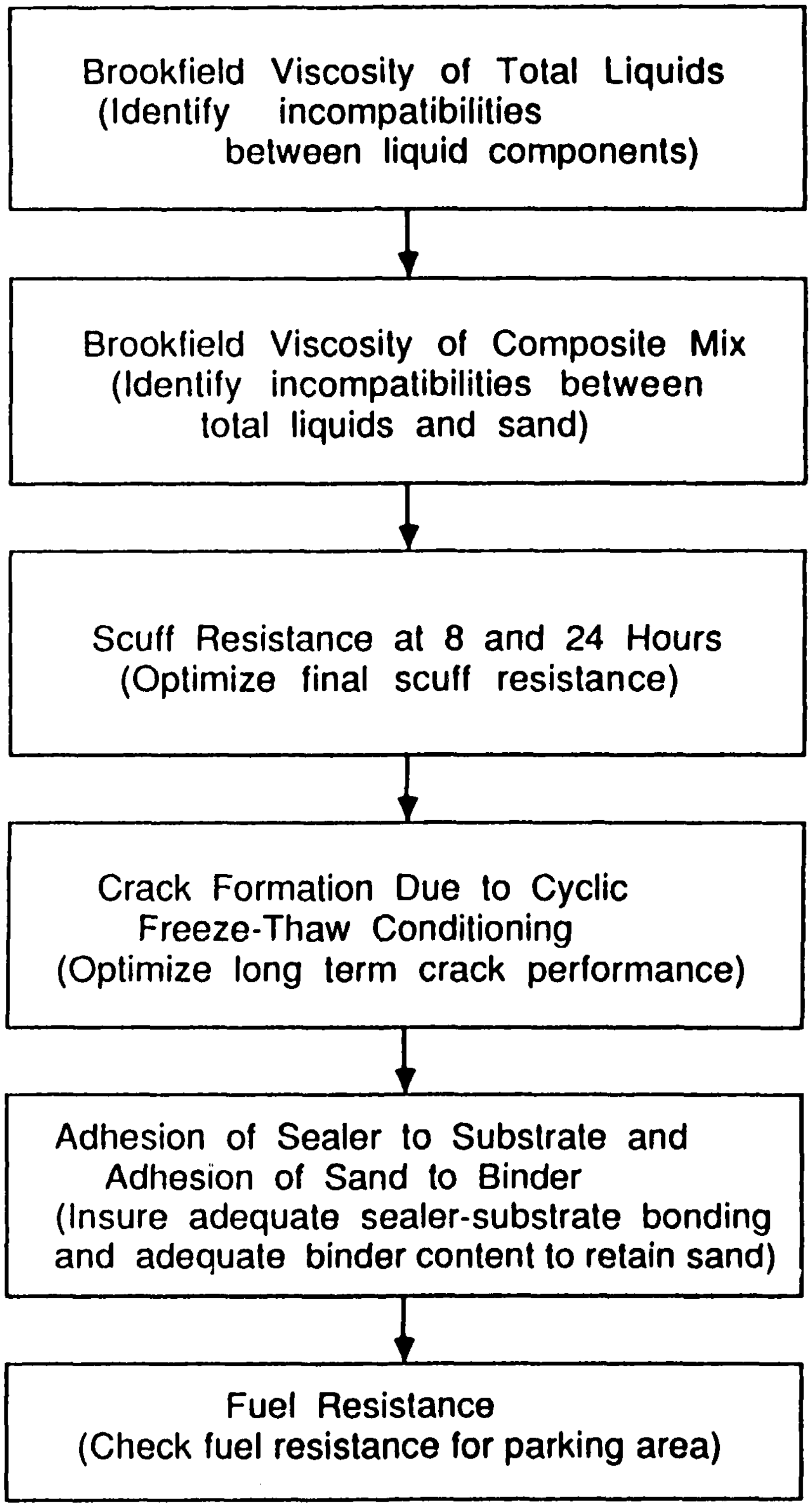


Figure 47: Determination of Optimum Component Quantities

This step also uses with viscosity measurements and visual observation to judge the acceptability of trial mixes. Viscosities between 10 and 90 poises are acceptable. Any mixtures not meeting this requirement will be eliminated from Step 3.

Step 3: The torque or scuff test is performed on mixes selected in step 2. A maximum of 8 hours is allowed for setting of seal coat. An high torque value at 24 hours indicates good scuff resistance for the materials used. Torque values equal to or greater than 100 in-pounds at 8 hours are acceptable. A small variation can be tolerated as long as it is within the realm of repeatability tolerances.

The results from this step have usually narrowed the acceptable combinations of components to approximately four to six. The mixtures not meeting these requirements are eliminated from the Step 4 test matrix.

Step 4: This step uses the freeze-thaw test to check on cracking potential. Long term performance cam be optimized by limiting the 5 and 10 cycle cracking in the cyclic freeze-thaw test. A rating of 1 or less at 5 cycles, and 3 or less at 10 cycles, is acceptable.

Step 5: Sand must be retained by the seal coat after it is cured, using the adhesion test as a pass-fail criteria. No sand can adhere to the tape, and no debonding of the seal coat from the test medium is allowed (adhesion rating 5A). Compositions that meet this test also should provide adequate resistance to the freeze-thaw test.

Step 6: Check the fuel resistance of the final mix.

If the seal coat is to be used in an area where high fuel resistance is required, a "pass" rating in the fuel resistance test should be required. Mixes not meeting this criteria should be redesigned, or should be used in areas where fuel resistance is not critical.

The adhesion test is important, because some mixes might pass all previous criteria, but fail to retain sand. Failure in this test will require that new formulations be tested.

The process, described above may produce only a preliminary estimation of component quantities, if a wide range of component levels are chosen initially. After the preliminary quantities have been found, using a wide range in component levels, another estimate should be made using a more narrow range of variables before selecting a final formulation.

CHAPTER V FIELD TEST RESULTS

INTRODUCTION

Two different sets of field test pads were placed during the study. The first set was placed on an eight-month old asphalt parking lot at the University of Nevada at Reno in September, 1986, before the laboratory study had begun. The second set of field test sections was placed in August and November, 1988, after the laboratory program had been completed. These sections were placed at Stead Airport, Reno, Nevada on an active taxiway and an abandoned taxiway.

FIELD TEST SECTIONS

Phase 1 - Field Test Sections at University

Before starting the laboratory testing program, major coal tar suppliers were invited to place field test sections on the University campus. The test sections were placed on a low traffic volume parking lot so weathering effects could be monitored without the influence of traffic loads. The parking lot chosen was approximately eight months old and provided a large, uniform surface for the application of the test sections.

Field samples were collected for laboratory cyclic freeze-thaw analysis by taping asphalt roofing shingles to the pavement prior to test section application. Samples were removed after 24 hours of field curing and returned to the laboratory.

Seventeen field test sections of varying sizes were placed by four suppliers in September, 1986. The mix formulations for the materials placed as test sections can be found in Table 3.

The test sections were visually monitored once a month for crack development. The scale used to monitor the cracking included: no cracking, hairline, slight, moderate, and severe cracking. This was the only testing which was performed at the field test site.

Samples of materials from the phase 1 field sections were used in the laboratory study program.

Phase 2 - Field Test Sections at Stead Airport

At the completion of the laboratory testing, the coal tar suppliers were invited to place test sections at the Stead general aviation airport. Stead is approximately 15 miles north of Reno. The test sections were placed on the taxiway "B" which had been overlaid 2-3 years previously. The overlay exhibited some reflection of the transverse cracks from the underlying pavement.

The purpose of this phase of the field work was to verify the mix design procedure developed in the laboratory phase of the research. Each supplier was requested to apply a mixture which met the criterion developed in the laboratory phase of the research. Each supplier was requested to apply a mixture which met the criterion developed in the laboratory phase of the research. Each supplier was requested to apply a mixture which met the criterion developed in the laboratory program at the University of Nevada-Reno (UNR), plus a composed mix recommended by the suppliers quantities.

Eight field test sections were placed by four suppliers on August 12, 1988. For comparison purposes, the construction procedure (ie. use of a prime coat, application rate, and use of a top coat) were constant for the University of Nevada-Reno (UNR) formulations. The suppliers construction procedures were consistent with their recommendations. The size of each test section was maintained at 150 square feet. The mix formulations for the materials placed as test sections can be found in Table 53.

In addition to the eight regulated test sections, each supplier was allowed to apply any mix formulation or research material to an additional 150 square foot area. These materials and formulations are shown in Table 54.

Skid Resistance Test Sections at Stead Airport

Of particular interest is the influence of the sand loading (quantity) on the skid resistant properties of the coal tar sealers. to examine this influence, four test sections were placed on an abandoned taxiway at the Stead Airport and the friction resistance measured using the Federal Aviation Administration (FAA) SAAB friction device. Each test section was 200 feet long and 10 feet wide and all sections were applied by the same supplier. The formulations for there sections are given in Table 55. Test section 1 consisted of Pavement Dressing Conditioner, which is a rejuvenating agent that penetrates the pavement. Test sections 2,3, and 4 contained 5,8 and 16 pounds of sand per gallon of coal tar emulsion respectively. The water and additive contents were held constant at 80 and 10 gallons per 100 gallons of coal tar emulsion respectively.

FIELD TEST RESULTS

Phase 1 - Field Test Sections

Cracking was observed for over two years on the initial field sections placed on a University parking lot. Laboratory freeze-thaw tests were continued for 10 cycles. Results of the observations are summarized in Table 56, after one and two years of field weathering, and 5 and 10 cycles of freeze-thaw conditioning in the laboratory. The data included in Table 56 represent the performance in both cases, and show reasonable good correlation between the field observations and the laboratory test results.

Table 53 Field Test Section Formulations Phase 2, Stead Airport Sections

Source/ID	Prime coat	No. of Base	Top Coat	Coal Tar gal	Additive gal	Water gal	Sand lbs
Source 1							
F1*	Water	2	N	100	14.5	55	8
F2**	N	2	Y	100	10.0	80	16
			top coat	100	4.0	80	----
Source 2							
F3*	Water	2	N	100	14.5	20	8
F4**	N	2	N	100	0.0	10	4.8
Source 3							
F5*	Water	2	N	100	4.0	90	8
F6**	Tarloc	2	N	100	4.4	90	4
Source 4							
F7*	Water	2	N	100	4.0	90	8
F8**	Tarmax/ Water	2	N	100	6.25	25	7

* - University of Nevada - Reno Formulations
** - Suppliers Formulations

Table 54 Experimental Test Section Formulations Phase 2, Stead Airport Sections

Source/ID	Prime Coat	No. of Base Coats	Top Coat	Coal Tar	Additive gal	Water gal	Sand lbs
Source 1							
EX 1A	N	1	N	100	6.0	50	8
		1		100	4.0	50	4
EX 1B	N	2	Y	100	10.0	80	17.3
			top coat	100	4.0	80	0
EX 1C	N	2	N	100	0.0	20	6
Source 2							
EX 2	N	1	N	---------	ACRI-SEAL	---------	
Source 3	Y*	2	N	100	----- PROMAK	-----	15
Source 4							
EX 4	Y**	2	N	100	---	16.6	6

* - Half of test section was primed with Tarlic, and half with Promak and water (50/50)

** - Jennite and water (50/50)

Table 55 Skid Test Section Formulations, Phase 2, Stead Airport Sections

Section	Prime Coat	No. of Base Coats	Top Coat w/o Sand	Coal Tar gal	Additive gal	Water gal.	Sand lbs*
1	No	---------- Pavement Dressing Conditoner ----------------					
2	Yes**	1	Yes	100	10	80	5
			Top Coat				
3	Yes**	1	Yes	100	10	80	8
			Top Coat	100	10	80	0
4	Yes**	2	Yes	100	10	80	16
			Top Coat	100	10	80	0

* - Pounds per gallon coal tar emulsion
** - Prime Coat - 50 percent water, 50 percent coal tar emulsion

Table 56 Comparison of Field and Laboratory Cracking,- Phase 1, University Sections

Section No.	Crack Rating			
	Field Sections After		Lab Samples After	
	One Year	Two Year	5 Cycles	10 Cycles
1	3	4	2	4
2	0	3	1	2
4	0	2	2	2
8 with top coat	3	4	2	2
8 w/out top coat	2	4	2	2
9 with top coat	3	4	4	4
9 w/out top coat	3	3.5	2	4
12	1	3	1	3
13	1	3	1	3
14	1	3	2	3
15	2	3	2	3
16	2	4	2	3
17	1	3.5	2	2

Cracking Rating System

0 - No Cracking
1 - Hairline Cracking
2 - Slight Cracking
3 - Moderate Cracking
4 - Severe Cracking

Phase 2 - Field Test Sections at Stead Airport

One week prior to application of the seal coats at Stead Airport samples of the proposed mix formulations were prepared in the laboratory and tested using the test procedures developed in the study. The following tests were performed: Brookfield viscosity, scuff resistance, cyclic freeze-thaw, adhesion and fuel resistance.

Samples of seal coat mixtures also were taken at the field site for transport to the laboratory for similar testing. In addition, Brookfield viscosity measurements were made on site in the field. Comparative results between the laboratory and field samples are presented and discussed below.

Viscosity

Viscosity measurements were determined on the coal tar emulsion, water and additive components (total liquids) and on the mixture after sand was added (composite system). Results of this part of the testing program at Stead Airport are shown in Table 57. Correlations appear to be good between measurements on the two different sets of samples, except in the case of test section F7 where excessive mixing in the field reduced the viscosity of the seal coat mixture. All viscosity values were low, but, except for those from sections F7 and F8, were within the recommended limits.

Scuff Resistance

Torque values from the scuff test for both laboratory and field samples are given in Table 58. Good correspondence was obtained between laboratory prepared and field samples; and scuff values for all mixes were equal to or exceeded the recommended limits after 4 hours of curing.

Adhesion Test

Data obtained from adhesion and fuel resistance tile testing on field and laboratory samples are summarized in Table 59. Adhesion test ratings of 5A, meeting the recommendations, were found for all samples tested; however, many of the emulsion mixes tested did not meet the recommendation regarding sand retention in this test. Possible loss of sand from future traffic action must be considered for these mixes. The possible benefits of the application of a top coat was not included in the study, and should be considered in assessing he significance of the results reported for these seal coats mixes.

Field Resistance Tile Test

Data is included in Table 59 for the fuel resistance test. Results of this test are somewhat inconclusive, in that one mix failed in the laboratory sample but the field sample passed. One additional field

Table 57 Viscosity Values for Total Liquids and Composite System, Phase 2, Stead Airport Sections

Field Test Sections	Viscosity (Poises) (1) Total Liquids only		Composite System with sand	
	Lab	Field	Lab	Field
F1	27.6	(2)	22.0	27.2
F2	(3)	(2)	(3)	29.4
F3	26.4	21.6	30.0	21.8
F4	(3)	21.2	(3)	27.8
F5	30.0	33.2	36.8	35.0
F6	(3)	26.8	(3)	34.4
F7	16.3	8.3 (4)	15.0	5.8 (4)
F8	(3)	10.7	(3)	9.1

(1) - Recommended limits, 10 to 90 poises
(2) - Unable to get measurement due to mixing sequence
(3) - Lab samples not prepared for
(4) - Low field viscosity due to severe mixing

Table 58 Scuff Test Results, Phase 2, Stead Airport Sections

Field Test Section	Torque (in-lbs) (1)					
	Lab Mix			Field Mix		
	4	8	24	4	8	24
F1	155	180	195	100	170	180
F2	(2)	(2)	(2)	150	175	215
F3	80	100	160	130	120	180
F4	(2)	(2)	(2)	110	150	200
F5	115	170	225	110	170	225
F6	(2)	(2)	(2)	120	160	175
F7	100	115	200	100	120	175
F8	(2)	(2)	(2)	110	170	205
EX1						
A	(2)	(2)	(2)	120	165	190
B	(2)	(2)	(2)	100	125	205
C	(2)	(2)	(2)	100	145	180
EX3	(2)	(2)	(2)	150	225	220
EX4	(2)	(2)	(2)	100	100	150

(1) Recommended limits: 8 hour torque $\geq$ 100 in-lbs
24 hour torque > 8 hr torque

(2) Lab samples not prepared

Table 59 Adhesion and Fuel Resistance Test Results, Phase 2, Stead Airport Sections

Field Test Section	Adhesion (1)		Tile Test (2)	
	Lab	Field	Lab	Field
F1	5A	5A	P	P
F2	(3)	5A+	(3)	P
F3	5A	5A	P	P
F4	(3)	5A	(3)	P
F5	5A	5A	F	P
F6	(3)	5A	(3)	P
F7	5A+	5A	P	P
F8	(3)	5A	(3)	P
EX1				
A	(3)	5A+	(3)	P
B	(3)	5A+	(3)	P
C	(3)	5A	(3)	P
EX3	(3)	5A+	(3)	P
EX4	(3)	5A	(3)	F

(1) Recommended Rating of 5A, with no sand loss

(2) Recommended all mixes pass for maximum fuel resistance

(3) Lab samples not prepared

\+ - Indicates sand was removed with tape

sample failed the test, but no corresponding laboratory sample was available for making comparisons. The data indicate that, in general, the mixes were reasonably fuel resistant.

Cyclic Freeze-thaw Test

Three sets of samples were taken or prepared for testing using the cyclic freeze-thaw test procedure: samples mixed and prepared entirely in the laboratory, samples taken in the field and taken to the laboratory for testing, and samples actually prepared in the field by placing the test medium, asphalt shingles, on the pavement surface before the coal tar emulsion seal coat was applied. Results of this series of test are given in Table 60. Although only limited data are available for the sampled mixed in the laboratory, there is reasonable correspondence between the three sets of data.

Only three months of exposure to weathering was available for field observations of cracking. Results of this limited period of observations are given in Table 61. Some cracking appeared to be developing after three months, but no conclusions regarding future performance is justified.

Friction Tests

Results of friction tests made on the special skid test sections constructed at Stead Airport are given in Table 62. Dry friction values are quite high for all speeds and mixes included in the test. However, wet friction values were lower in all cases for sections where coal tar emulsion seal coats had been placed. The data indicated that wet friction values were affected by sand content of the seal coats, with reductions of 4 to 5 points corresponding to sand content increases from 5 to 16 pounds. All seal coat friction values were reduced considerably by increasing the test speed from 40 mph to 60 mph.

FINDINGS FROM THE FIELD STUDIES

The field studies included in this project were designed to provide information about coal tar emulsion seal coat materials and formulations used in practice in the United States, including general aviation airports. The materials were included in the laboratory experiments, and observations of their construction an performance under real weathering conditions was used to help set criteria for the test procedures recommended for use in practice.

Although formulations and materials differed greatly among sources, and field cracking observations reported in Table 56 indicated that there were noticeable differences between the mixes, no strong evidence as shown that some mixes were superior to others. Unfortunately, most sections in phase 1 experiment at the University displayed a fairly high degree of cracking after two years of exposure.

Table 60 Laboratory Cyclic Freeze-Thaw Conditioning Results for 1, 5, and 10 Cycles, Phase 2, Stead Airport Section

Field Test Section	Cracking Rating (1)								
	Lab Mix			Field Mix In Lab (3)			Field Mix in Field (4)		
	1	5	10	1	5	10	1	5	10
F1	0	1	1	0	0	0	0	1	2
F2	(2)	(2)	(2)	0	0	1	0	1	2
F3	0	1	1	0	1	1	0	0	2
F4	(2)	(2)	(2)	0	2	2	0	1	2
F5				0	1	2	0	0	1
F6	(2)	(2)	(2)	0	1	2	0	1	2
F7	0	1	2	0	1	2	0	1	2
F8	(2)	(2)	(2)	0	1	2	0	1	2
EX 1									
A	(2)	(2)	(2)	0	1	1	0	0	1
B	(2)	(2)	(2)	0	0	0	0	0	0
C	(2)	(2)	(2)	0	1	0	0	1	1
EX 3	(2)	(2)	(2)	0	0	0	0	0	0
EX 4	(2)	(2)	(2)	0	2	3	0	1	3

(1) Recommended ratings: $\leq$ 1 @ 5 cycles
$\leq$ 3 @ 10 cycles

(2) Lab samples not prepared
(3) Samples mixed in the field and applied to shingle in the lab
(4) Samples mixed and applied in the field and brought back to lab

Table 61 Field Test Section Cracking, Phase 2, Stead Airport Sections

Field Test Section	Sept. 88	Oct. 88	Nov. 88	Dec. 88
F1	0	0	0	0
F2	0	0	0	0
F3	0	0	0	0
F4	0	0	0	0
F5	0	0	0	0
F6	0	0	0	0
F7	0	0	0	0
F8	0	0	0	0
EX1A	0	0	0	0
EX1B	0	0	0	0
EX1C	0	0	0	0
EX 2	0	0	0	1
EX 3	0	0	0	0
EX 4	0	0	0	1

0 - No cracking
1 - Hairline Cracking
2 - Slight Cracking
3 - Moderate Cracking
4 - Severe Cracking

Table 62 Results of Skid Resistance Testing Performed at the Stead Airport Sections

	Test Section*				
	1	2	3	4	5
Dry					
20 (mph)	.99	.99	.99	.99	.99
40 (mph)	.97		.97	.96	.98
60 (mph)	.94	.90	.95	.95	.96
Wet					
40 (mph)	.78**	.72**	.64**	.67**	.94**
60 (mph)	.70**	.52**	.52**	.48**	.81**

* - Test Sections

1 - Pavement Dressing Conditioner
2 - 5 pounds sand, 80 gal water, 10 gal additive
3 - 8 pounds sand, 80 gal water, 10 gal additive
4 - 16 pounds sand, 80 gal water, 10 gal additive
5 - control section

** - Values indicate the average of the west and east direction readings

The sections placed at Stead Airport in Phase 2 indicated that the testing procedures and mix design method developed in the study can be used to design mixes that can be placed successfully.

Test measuring viscosity, scuff resistance, resistance to freeze-thaw cracking, adhesion and fuel resistance were successfully performed on samples of materials taken in the field and transported to the laboratory. Viscosity measurements were successfully made in the field. All of these tests can be used for quality assurance testing, although the effects of storage time have not been determined.

The amount of sand in the mix used for skid testing did not appear to affect friction values appreciably, although the coal tar seal coat did have lower friction values than the pavement without a seal coat application.

The experiences gained working with field mixes at the University and at Stead Airport contributed in a large measure to the findings and recommendations developed in this study. It is recognized that the findings reflect a relatively short time period for field performance observations, and for only one set of environmental conditions. However, the experiment did include a wide range of materials from different commercial sources, and the suppliers of the materials included in the field studies were invited and encouraged to comment and offer advice as the study proceeded.

CHAPTER VI REVIEW AND SUMMARY

REVIEW OF FINDINGS

A number of cases of severe cracking in coal tarqemulsion seal coats were cited in the state-of-the-art survey conducted as part of this study. Such cracking has been attributed to reflection of both visible and invisible cracks in the underlying asphalt pavement, shrinkage of the coal tar emulsion seal coat, placing the seal coat on insufficiently cured new asphalt pavement, use of coatings that are too thick, or incorrect formulations. Sometimes the cracks appear within a few weeks of placing the seal coat, or they may not become evident for several months.

In addition to cracking, cases of low skid resistance and poor adhesion were cited. In general, these problems appear to have been related to incorrect formulations or incorrect construction practices.

Item P-625, Article 3.3, TEST SECTION, stipulates that prior to full production a test section of approximately 50 square yards of mixture in the proportions specified for the job shall be placed and evaluated to verify the adequacy of the proposed mix composition, application rate, placement operations, and equipment. Indications are that in many cases the placement and evaluation of test sections prior to construction of the seal coat would have helped determine whether or not problems of cracking, poor adhesion, or other difficulties would have occurred.

Therefore, it was recommended at the conclusion of the state-of-the-art survey that test sections be placed on a representative section of all pavements for which sealing is scheduled and that these test sections be observed for at least one month before construction of the seal coat on the remaining pavement. In many cases it may be necessary to construct test sections with different application rates, different formulations, and with and without a prime coat or top coat (without sand) to determine the optimum composition and application rate for the particular conditions applying to a given pavement surface.

Several replies to a survey conducted by an FAA regional office, and private conversations with engineers responsible for seal coat construction, have indicated that close supervision by a qualified inspector on the job may be required to insure proper application of coal tar emulsion seal coats. Item P-625 is somewhat vague regarding requirements for contractor certification of the final mixture, as applied, and does not include any requirement for on-site inspection. Pending development of applicable quality control testing procedures for coal tar emulsion seal coats, it was recommended that on-site inspection and contractor certification be required to insure that the mixture as applied meets the specified composition and application rates. Pre-certification of contractors also was suggested.

A number of conflicting claims were made by industry representatives and others regarding the adequacy of seal coat formulations and application rates specified in Item P-625. In addition, new polymeric additives that did not meet P-625 requirements were being introduced. One of the objectives of this research project was to develop tests and applicable criteria that might be used to specify coal tar emulsion sealers for airport pavements. Pending development of such procedures and criteria, it was recommended that deviations from P-625 requirements for materials be permitted provided the supplier can produce documented evidence, satisfactory to the FAA, that the proposed product has been applied and performed satisfactorily under similar conditions for a period of four to five years.

The above recommendations were made before the laboratory testing program had been completed. The testing program included two field studies and a laboratory testing program. The laboratory testing program was conducted in several phases. The first phase included a large factorial experiment in which the variables included different formulations of coal tar emulsion, latex additive, water and sand quantities. The experiment also included fine and coarse graded sands and sands that were both rounded and angular. A statistical study of the data from this phase of the experiment indicated that sand gradation and sand angularity had very little influence on test values; and these variables were dropped from the second phase experiment.

However, different sources of latex rubber additive had a large influence on the behavior of the formulations in this phase and all other phases of the experiment. This finding was significant. It was clear that all latex rubber additives that met FAA P-625 specification requirements did not produce the same formulation of coal tar emulsion, latex, water and sand. In fact, most of the formulations placed by suppliers in the first field study did not meet P-625 requirements in all respects.

It appeared desirable, therefore, to concentrate the laboratory study on the development of test procedures that would reflect such properties of coal tar emulsion seal coats as workability, and resistance to cracking, scuffing, loss of adhesion and poor fuel resistance, rather than tests that would reflect adherence to specific mixture composition.

It was not possible in this experiment to investigate all possible variables that might affect coal tar emulsion seal coat performance. The experiment, however, did include investigation of incompatibility between the coal tar and latex additives, workability of the mixes, rate of set, resistance to scuffing, resistance to cracking, adhesion properties, and fuel resistance. Use of the recommended test procedures for mix design and quality control testing should indicate relative ability of various coal tar emulsion seal coat formulations to resist these forms of distress.

APPLICATION OF FINDINGS TO PRACTICE

The application of the results of the experimental work done in this study to making formulations of coal tar emulsions, water, rubber latex

additives, and sand using a mix design procedure were demonstrated by using the procedures to design the mixes placed in the field sections at Stead Airport, Reno, Nevada. Although the mixes did not conform, in all cases, to those recommended by the industry representatives, satisfactory formulations were prepared and satisfactorily placed.

The possible use of test procedures for quality assurance testing were shown, also, by the testing done for the field test installations placed at Stead Airport. Comparisons of test values obtained on laboratory samples before construction were compared to test values obtained on samples of sealers obtained in the field. The comparisons showed that field samples could be transported to the laboratory for testing, and that comparable results could be obtained and used for quality assurance testing.

Also of significance were findings or indications from the testing program that some of the differences between suppliers might not be of significance in setting specification requirements, if a specification based on proposed test criteria for coal tar emulsion seal coats is adopted.

Major differences were noted between recommendations by different suppliers for sand loading and sand gradation. Some suppliers preferred low sand loadings and fine graded sands; others preferred high sand loadings and coarse graded sands. While some differences were noted in test results, no practical differences were detected between the fine sand gradations and the coarse sand gradations, or for sand loadings between 2 and 16 pounds per gallon of emulsion.

Significant differences were noted between quantities of latex from different suppliers required to produce similar test results. For example, it was not possible to produce acceptable mixes using the same formulations for all latexes supplied to the project. However, acceptable mixes were made using all materials by varying the formulations to suit the individual material characteristics.

Similarly, claims are made that the particle size of the rubber latex additives is important, and that extremely small particle sizes produce better results. Unfortunately, the project was not able to include this as an experimental variable in the laboratory study. It should be noted, however, that the mixes used in the experiment included latex additives with a wide range of particle sizes, and there is no evidence that particle size affected seal coat performance.

The presence or absence of silicones in the formulations was reported to have a beneficial effect on coal tar emulsion sealer performance. It was not possible to include silicones as an experimental variable in this study. However, some of the mixes included in the program contained a silicone; and no difference in performance between these mixes and those without a silicone could be detected. It should be noted, however, that a

field installation reported in Volume I of this report included one unsuccessful application of a non-proprietary seal coat that incorporated a silicone ingredient.

Cracking was found to be a major cause of distress in coal tar emulsion seal coats. Formulations can be designed to minimize cracking; however, thickness of the application and other factors were found in the state-of the art survey to be important. It is recommended that requirements for application rate to be investigated, to determine under what conditions it might be necessary to limit applications rates to prevent the use of thick coatings that might have a greater tendency to crack than thinner coatings. It can be inferred from this study that acceptable application rates will depend on sand gradation and sand loadings, with greater application rates being permitted for larger size sand and higher sand loadings. There is a slight indication that the addition of a top coat also can increase cracking in some cases. Unfortunately, the study did not yield definitive answers to these questions.

There are indications from this study that some severe cracking problems are caused by a basic incompatibility between the underlying asphalt pavement and the coal taremulsion seal coat. Asphalt pavement surfaces that have not been exposed to hot temperature weathering appear to be more susceptible to such cracking than older surfaces. Small test sections, placed by hand, should be able to detect potential incompatibilities of this type.

The longest time period available at the time of this report for observing performance of the field test sections placed as part of this study is 27 months, corresponding to construction of the first set of field test sections at the University of Nevada. The second set of field sections at Stead Airport were less than three months old. All of the first set of sections had cracked during the preceding 27 months, while none of the second set exhibited cracking. It is possible, of course, that during the next two or three years differences in performance of the test sections will occur.

MIX DESIGN AND QUALITY ASSURANCE TESTING

A major result of this investigation was the development of a mix design procedure for coal tar emulsion seal coats. The procedure can be used to formulate mixtures of coal tar emulsions, water, rubber latex additives, and sand that meet criteria, also developed in the study. The procedure includes test methods, test criteria, and a sequence of steps for selecting optimum quantities of the different components of coal tar emulsion sealers. The procedure is sufficiently well developed that it can be used on a trial basis to check properties of coal tar emulsion seal coat formulations proposed for use on general civil aviation airports in the United States. The test methods, test criteria and steps in the mix design procedure are given in Chapter IV and Appendix B of this report.

Poor workmanship and poor construction control have been cited as causing excessive cracking, loss of adhesion and other forms of distress. On-site inspection or quality control testing may be required in many cases to prevent these occurrences. It has been demonstrated in this study, however, that it is possible to take samples of coal tar emulsions obtained during construction to the laboratory for testing, and to obtain results that match those obtained from laboratory prepared samples. Field samples could thus be taken and stored for a short time as a possible check where satisfactory results are not obtained during or shortly after construction.

A particularly rapid and relatively inexpensive test that will measure mix viscosity, an important property that can detect major discrepancies between the formulation being used and the one specified, uses the Brookfield viscometer. A proposed test procedure and recommended test criteria using the Brookfield viscometer are given in Appendix A and Appendix B of this report.

LIMITATIONS OF THE RESEARCH

The results of this study were produced from a relatively small study of the many variables that might affect the performance of coal tar emulsion seal coats; and field performance data is limited. However, the proposed test procedures were developed from tests used for other products, and tests were performed on coal tar emulsion seal coats that represent the major sources currently used on general aviation airports. It is considered on this basis that the results of this study can be used to develop a new specification for coal tar emulsion seal coats based on the test procedures and criteria developed in the study, and distributed for trial use.

It was not possible to investigate all possible factors that affect the performance of coal tar emulsion seal coats. In particular, the recommended viscosity limits need to be checked under field conditions using commercial spray and squeegee operations, rather than the hand procedures used in this investigation. The use of other polymers than A-B rubber latex have been proposed, and should be investigated. Particle size of polymeric additives need additional research to develop realistic limits. The use of silicones is permitted, but the limits of their use need further attention. Experiences reported in the survey performed in this study indicated that low friction values can be produced if care is not taken in formulating mixtures that contain silicones.

Cracking of coal tar emulsion sealers was the most prevalent form of distress found in the survey. Cracking can be a major problem where high resistance to fuel spills is required. Various factors have been cited as causes of cracking. Unfortunately, few solutions have been proposed. The mix design procedure developed in this study includes a test that will help to design formulations that will have some degree of crack resistance. Additional research is needed to isolate those characteristics of both the coal tar emulsion seal coat and the pavement surface that have a major effect on cracking of sealers.

SUMMARY OF CONCLUSIONS

Results of the state-of-the-art review, published in Volume I of this report, indicated that problems with scuffing, cracking, poor friction characteristics, poor adhesion, and poor construction control are often encountered in actual practice.

Most coal tar sealers used on airport pavements are sold as proprietary products. Formulations, types of additives, and sand loadings vary, and optimum formulations are not agreed upon by all suppliers.

The survey indicated that there was a need to develop test procedures that could be used to design seal coat formulations and that could be used for construction quality assurance purposes.

Not all formulations permitted by the current Item P-625 specification produced acceptable mixtures in this study. On the other hand, some mixes that did not conform to Item P-625 were acceptable.

The type and amount of latex additive was a highly significant factor in producing satisfactory seal coat formulations. The laboratory study revealed that incompatibilities exist between coal tar and latex additives. Some quantities of all additives produced mixes that were too thick to use.

The amount of water was significant. Too much water produced mixes that were too thin to use. Some combinations of water and latex that did not fall within the Item P-625 limits produced acceptable mixes.

Sand type and gradation had no significant effect on the test results included in the study. Sand quantities from 5 to 16 pounds per gallon of emulsion performed equally well in these tests.

A mix design procedure, which included measures of workability, rate of set, resistance to scuffing, cracking, adhesion, and fuel resistance, was developed and is available for publication and trial use. The procedures are included in Appendix A and Appendix B of this report.

The mix design procedure was used to demonstrate that mixes could be prepared using lower amounts of latex additive than the minimum of 0.07 gallons per gallon of emulsion or more than the maximum of 0.12 gallons given in Item P-625.

A relatively simple procedure using the Brookfield viscometer to measure viscosity was developed and can be used as a construction quality assurance test.

CHAPTER VII RECOMMENDATIONS

This study included a state-of-the-art survey of the use and performance of coal tar emulsion sealers, and research into the properties of coal tar emulsion seal coat materials available from six different commercial sources. The research included both laboratory investigations and construction of field test sections. The major finding from the study are summarized and discussed in Chapter VI and in previous chapters.

The following recommendations are based on findings from the survey and from the laboratory and field research studies. Many results of this research can be used to modify Item P-625, Coal-tar Pitch Emulsion Seal Coat, currently distributed in Advisory Circular AC: 150/5370-10A, Standards for Specifying Construction of Airports.

It is recommended that Item p-625 be modified for trial use as follows:

1. Add the following note to Article 625-1.1:

NOTE

Improper formulations or poor construction control of coal tar pitch emulsion seal coats may produce coatings that crack, that do not adhere properly to the pavement surface, or that have low friction values.

The application of seal coats to pavement surfaces that have not been properly prepared or to new pavements that have not weathered sufficiently may cause cracking, curling or loss of adhesion.

2. Modify TABLE 1, Article 625-2.1 AGGREGATE to read as follows:

TABLE 1. GRADATION OF AGGREGATES

Sieve Size	Percent by Weight Passing Sieves Gradation A	Gradation B
No. 16 (1.18 mm)	100	100
No. 20 (0.85 mm)	85-100	100
No. 30 (0.60 mm)	15-85	98-100
No. 40 (0.40 mm)	2-15	90-98
No. 50 (0.30 mm)	-	44-75
No. 100 (0.15 mm)	0-2	5-24
No. 200 (0.074 mm)	-	0-3

3. Add the following to Article 625-3.1 COMPOSITION.

Rubberized coal-tar emulsion seal coat formulations are sensitive to the characteristics of individual latex additives proposed for use. Not all products will provide satisfactory seal coat formulations for all combinations of coal tar emulsion, water and rubber additive permitted by this note. The following test procedures and test criteria should be used to determine if a proposed formulation will produce a satisfactory sealer.

Test Method	Purpose	Criterion
Brookfield Viscosity poises @ 77°F	Incompatibility between additive and coal tar	Viscosity between 10 and 90 poises CV = 3.7%
Brookfield Viscosity poises @ 77°F	Workability of mix	Viscosity between 10 and 90 poises CV = 8.0%
Scuff Resistance	Rate of set	8 hour torque > 100 in-lbs
Scuff Resistance	Final scuff resistance	24 hour torque > 8 hour torque Std Dev = 15 in-lbs
Cyclic Freeze-Thaw Conditioning	Cracking	Rating < 1 @ 5 cycles Rating < 3 @ 10 cycles Std Dev = 0.29
Tape Test	Adhesion	Rating = 5A No sand loss
Tile Test	Fuel Resistance	Passes

Appropriate test procedure and method to be used in determining optimum quantities of water, sand and rubber are described in the following document:

Criteria for Coal Tar Seal Coats on Airport Pavements, FAA report DOT/FAA/DS 891

Sand quantities for rubberized sand slurry may be increased to 16 pounds per gallon of coal tar emulsion, provided the mixture meets the test criteria given above.

It may be necessary to use lower sand quantities for Sand Slurry mixes than specified in the table of compositions. This will provide proper adhesion qualities.

Application rates should be checked carefully using TEST STRIPS. Excessive application can promote cracking in the unfinished sealer.

4. Revise paragraph three of Article 625-3.3 TEST SECTION to read as follows.

Observe the test section for thirty days. If cracking or other unsatisfactory condition is observed, adjust the application rate and check the composition of the mix using the test procedures and test criteria given in Article 625-3.1 COMPOSITION.

5. Revise Article 625-4.3 PREPARATION OF PAVEMENT SURFACE to read as follows.

Bituminous pavement surfaces that have been softened by petroleum derivatives or that have failed for any other reason shall be removed to the full depth of the damage and replaced with new bituminous concrete similar to the existing pavement.

New bituminous concrete pavement surfaces shall be allowed to cure or weather before application of the seal coat. Insufficient curing can be determined by constructing a small test pad, approximately four-square yards in size, by hand application using the same coal tar [and additive] that is to be used for the contract. The test pad shall be observed for evidence of cracking, curling or other forms of distress for a minimum period of thirty days before applying the full amount of the seal coat to the pavement.

New pavement surfaces may exhibit evidence of insufficient curing or weathering if an oily film is seen after water has been standing on the pavement surface for a short while. A small test pad shall be constructed and observed as described above to determine if the condition will cause cracking or other undesirable performance of the seal coat.

6. Revise Article 625-4.7 CURING to read as follows.

The minimum curing time shall be that required to meet the scuff test requirements given in Article 625-3.1 COMPOSITION. Any damage to the uncured mixture shall be the responsibility ot the Contractor to repair.

7. Add a new Article 625-5.0 SAMPLING.

A one-quart sample of the seal coat mixture shall be obtained from each distributor load of coal tar emulsion seal at the time of application for use as quality assurance test samples in case of dispute or evidence of unacceptable performance. All samples shall stored in glass

containers, sealed against contamination and retained in storage for a period of six months. Samples shall be stored at normal room temperatures and not subjected to freezing temperatures.

Properties of samples from contested work shall be tested using the procedures given in Article 625-3.1 COMPOSITION.

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APPENDIX A
TEST PROCEDURES

BROOKFIELD VISCOSITY

1. Scope

This method covers the determination of the Brookfield fiscosity of a coal tar emulsion mixture.

2. Definitions

2.1 Brookfield viscosity - the viscosity determined by this method. It is expressed in centipoise (1 cp = 1mPa*s). Its value may vary with the spindle speed (shear rate) due to the non-Newtonian behavior of the coal tar emulsion, additive, and added water.

2.2 Total liquids - coal tar emulsion, additive, and added water.

2.3 Composite system - total liquids and sand.

3. Apparatus

3.1 Brookfield digital viscometer (model DV-II) and stand.

3.2 Number 1 and 3 HB spindles for HB DV-II model viscometer.

3.3 Paint cans (lids removed).

3.3.1 1 quart capacity.

3.3.2 1 gallon capacity.

4. Sample preparation

4.1 Allow components (coal tar emulsion, water, and additive) to reach 77°F. This should take approximately 24 hours.

4.2 Mix coal tar emulsion and water in container specified in 3.3.2 with 50 strokes of a large laboratory mixing spoon.

4.3 Introduce additive to the mixture with an additional 50 strokes of the mixing spoon.

5. Procedure

5.1 Fill quart paint can specified in 3.3.1 to within one inch of the top with material prepared in accordance with 4.1 through 4.3.

5.2 Insert spindle No. 3 HB in the material until the mixture level coincides with the immersion groove on the spindle shaft.

5.3 Avoid trapping air bubbles underneath spindle.

5.4 Adjust rotational speed on Brookfield viscometer to 50 revolutions per minute (rpm).

5.5 Start motor and record viscosity value in centipoise after five seconds of rotation. If the viscosity reading is to low for spindle 3, repeat procedure 5.1 through 5.5 using spindle No. 1.

5.6 Add sand to total liquids with 50 strokes of large laboratory mixing spoon.

5.7 Repeat procedure 5.1 through 5.5 on the composite mixture.

6. Report

6.1 The report should include

6.1.1 Date of test and complete identification of the coal tar formulation tested.

6.1.2 Spindle number and rpm setting.

6.1.3 Temperature of sample tested.

6.1.4 Viscosity of total liquids in centipoise.

6.1.5 Viscosity of composite mix in centipoise.

SCUFF RESISTANCE TEST

1. Scope

This method covers the determination of the initial set and final scuff resistance characteristics of coal tare emulsion seal coat.

2. Definitions

2.1 Initial set - torque reading at 8 hours of curing.

2.2 Final scuff resistance - torque reading at 24 hours of curing.

3. Apparatus

3.1 "Scuff" resistance tester (Figure 1), similar to the cohesion tester in ASTM D3910-80a but modified as follows:

3.1.1 Proving ring used to measure applied load.

3.1.2 Screw jack used to apply load.

3.1.3 5" X 3/4" ID 1 7/32" OD reinforced rubber hose (two braid, 300 psi, green, oil resistant cover).

3.2 Torque wrench with 300 in-lb capacity.

3.3 6" X 6" square 16 gauge sheet metal mask with 4" X 4"square center removed.

3.4 6" X 6" square class a asphalt or fiberglas roofing shingle.

4. Procedure

4.1 Using mask described in 3.3, apply uniform thickness of coal tar emulsion mixture to two shingles as described by 3.4.

4.2 Allow shingles to cure at 77^{o}F and 13-20 percent relative humidity.

4.3 Test the first shingle after 8 hours of curing.

4.4 Place shingle on lower platen and secure with "c" clamps.

4.5 Raise platen with screw jack until sample comes in contact with the rubber abrasion head.

4.6 Continue raising the platen until a normal load of 28 psi, as measured through the dial gage, is applied to the sample.

4.7 Tap platen to insure proper load is applied to the sample.

4.8 Pull torque wrench through and arc of 180 degrees in 1-2 seconds.

4.9 Record torques reading in inch-pounds.

4.10 Repeat procedures 4.4 through 4.9 on second sample after 24 hours of curing.

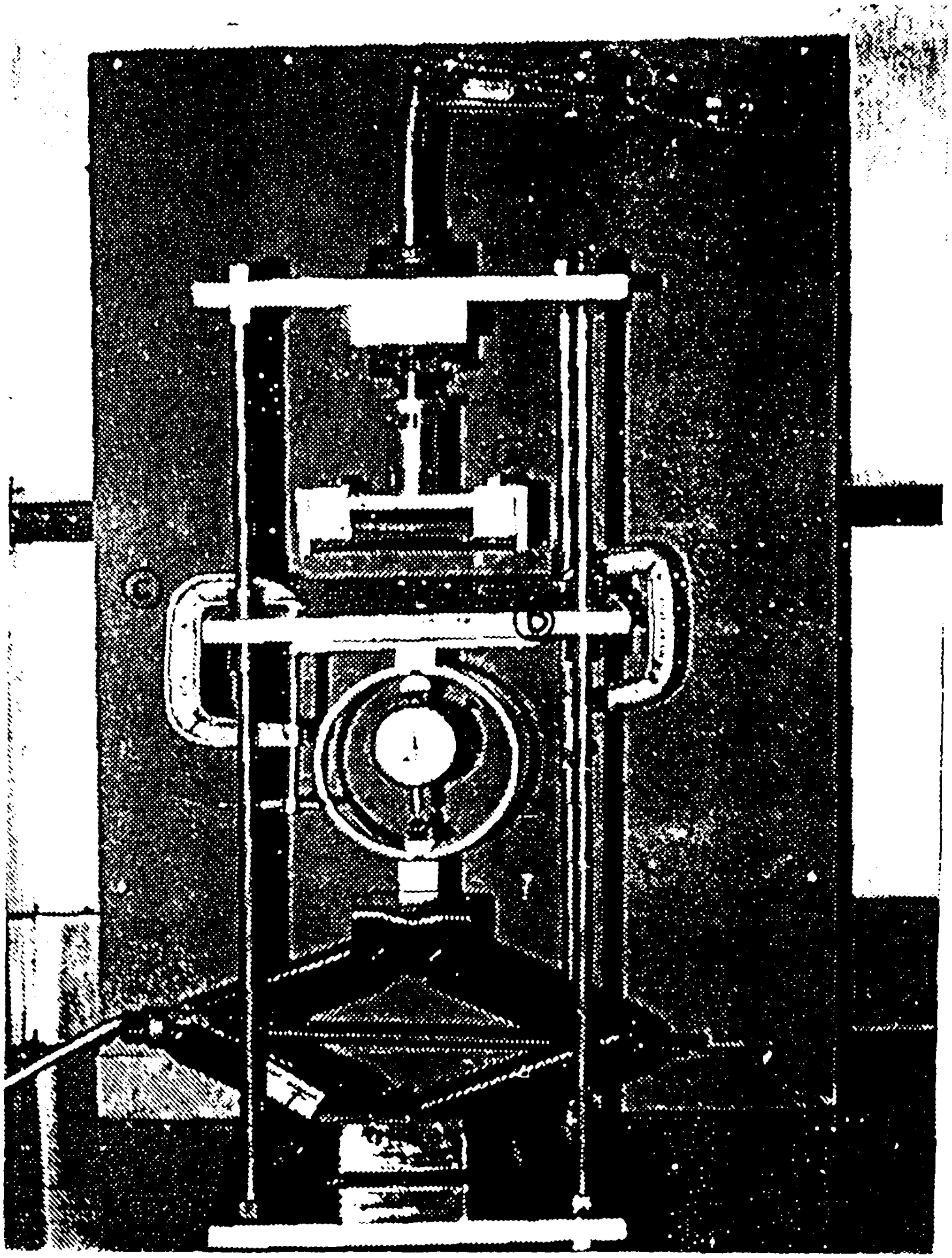
5. Report

5.1 Report the following information.

5.1.1 Date and material tested.

5.1.2 Initial set as the torque reading at 8 hours of curing.

5.1.3 Final scuff resistance as the torque reading at 24 hours of curing.



A - Rubber Abrasion Head
B - Torque Wrench
C - "c" clamps
D - Lower Platen
E - Dial Gage
F - Screw Jack

CYCLIC FREEZE-THAW CONDITIONING

1. Scope
   This method covers the analysis of crack development in a coal tar emulsion seal coat when exposed to multiple cycles of freezing and thawing.

2. Apparatus
   2.1 12" X 12" square 16 gauge sheet metal mask with 11" X 11" square center removed.
   2.2 12" X 12" square section of class A asphalt or fiberglass roofing shingle.
   2.3 Oven capable of maintaining 140°F.
   2.4 Freezer capable of maintaining 10°F.

3. Procedure
   3.1 Using mask described in 2.1, apply uniform thickness of coal tar emulsion mixture to a shingle as described by 2.2.
   3.2 Allow shingle to cure at 77°F and 13-20 percent relative humidity for 24 hours.
   3.3 Place sample in the 140°F oven for 24 hours.
   3.4 Remove sample and record crack development (use Figure 1 as a guide).
   3.5 Neglect cracks caused by asphalt "tabs" on surface of roofing shingle.
   3.6 Place sample on 10°F freezer for 24 hours.
   3.7 Remove from freezer, this constitute one freeze-thaw cycle.
   3.8 Repeat procedures 3.3 through 3.6 for a total of 10 cycles.

4. Report
   4.1 Report the crack rating at 5 and 10 cycles.

Severe Cracking	Rating = 4
Moderate Cracking	Rating = 3
Slight Cracking	Rating = 2
Hairline Cracking	Rating = 1

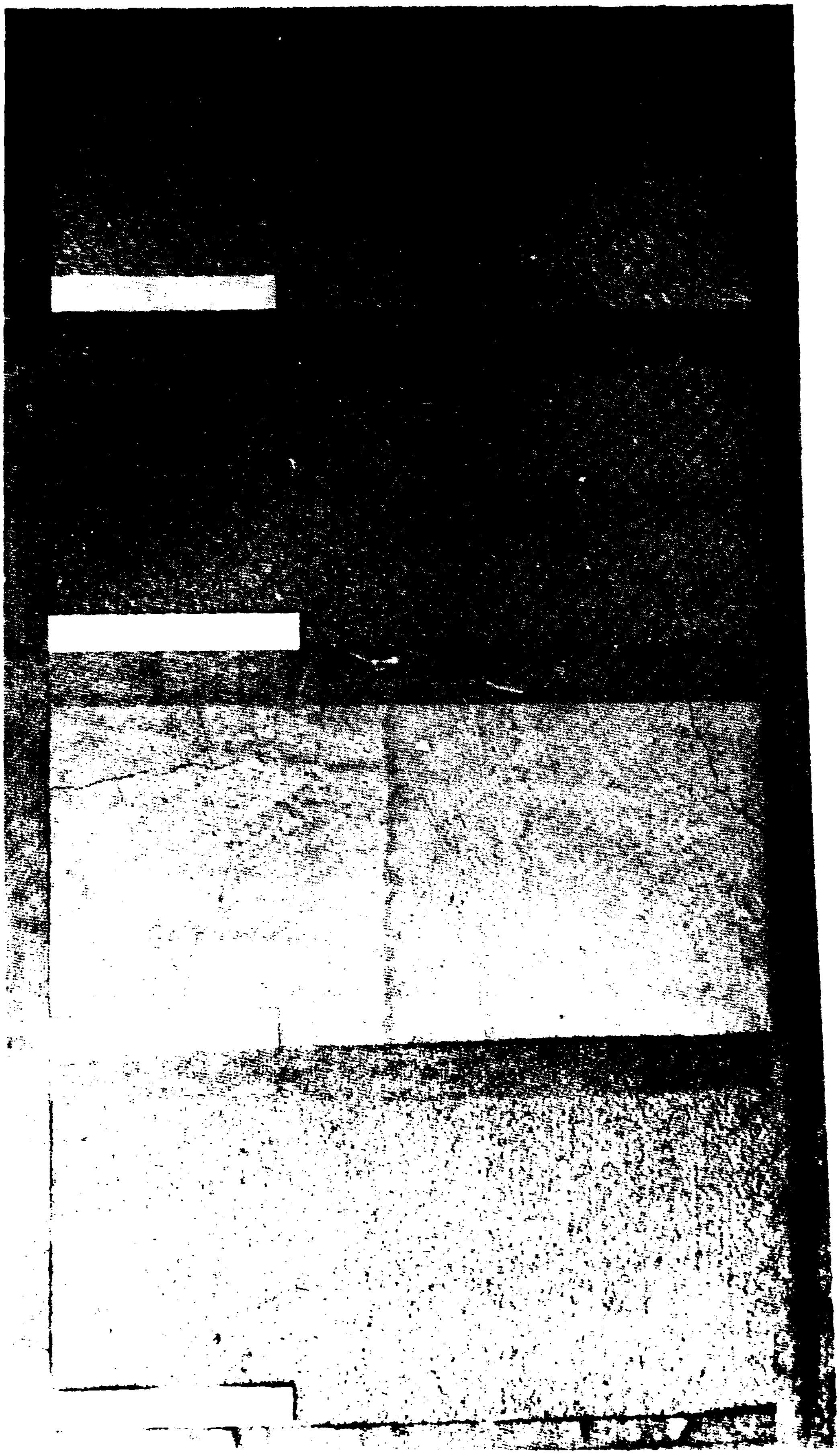


Figure A2 Crack Rating System for Cyclic Freeze-Thaw Conditioning Test

ADHESION TEST

1. Scope
   This method covers the determination of a coal tar seal coat adhesion by tape test.

2. Apparatus
   - 2.1 12" X 12" 16 inch gauge sheet metal mask with 3" X 6" rectangular center removed.
   - 2.2 12" X 12" square aluminum panel.
   - 2.3 Razor sharp blade, scalpel or other cutting devices with good cutting edges.
   - 2.4 Steel straight edge.
   - 2.5 Pressure sensitive tape of 38 oz $\pm$5/inch of width.
   - 2.6 Hard small head rubber eraser.
   - 2.7 Table lamp.

3. Procedures
   - 3.1 Using the mask described in 2.1, apply uniform thickness of coal tar emulsion mixture to an aluminum panel as described by 2.2.
   - 3.2 Allow panel to cure at 77° and 13 to 20 percent relative humidity for 24 hours.
   - 3.3 Pick a representative area and using a straight edge, make two cuts each 1.5 inch (40 mm) long to form a "X".
   - 3.4 First make a horizontal cut of 1.5" (40 mm) with a single motion. Then with one motion, make another 1.5" (40 mm) cut at about 40 degrees to the horizontal cut and make the cuts intersect each other at their centers.
   - 3.5 Place the cuts under the lamp to see the reflection of the light off the aluminum panel to ensure that the cuts are through all the way to the aluminum panel.
   - 3.6 If the cut is shallow, do not attempt to make the cut deeper. Instead make another "X" in a different location.
   - 3.7 Remove two laps of the tape with a slow pulling motion, then cut a piece of 3 inch tape.
   - 3.8 Place the length of the 3 inch tape across the narrower ends of the cuts with the center of the tape at the intersection of the cuts. Smooth out the tape and rub it with the eraser to ensure good bonding.
   - 3.9 Wait for 45 seconds then rapidly but steadily pull one end of the tape backward with the non-stick surfaces touching and running parallel to each other.
   - 3.10 Repeat the test twice at other locations on the test panel.
   - 3.11 Determine the conditions of peeling from scale of one to five.

5A - No peeling or removal of sand or coal tar.
4A - Trace peeling or removal along incisions.
3A - Jagged removal along incisions up to 1/16 in. (1.6 mm) on either side.
2A - Jagged removal along most of incisions up to 1/8 in. (3.2 mm) on either side.
1A - Removal from most of the area of the X under the tape.
0 - Removal beyond the area of the X.

4.0 Report

4.1 The report should include the number of sets of tests.

4.2 The mean value and the range of each set of the test.

TILE TEST

1. Scope
   This method determines the resistance of coal tar sealant to kerosene.

2. Apparatus
   2.1 6" X 6" square 16-gauge sheet metal mask with a 4" X 4" square center removed.
   2.2 6" X 6" unglazed white ceramic tile.
   2.3 Brass ring; 2" diameter and 2" height.
   2.4 Kerosene.
   2.5 Silicon rubber.

3. Procedures
   3.1 Immerse the ceramic tile in distilled water for a minimum of 10 minutes.
   3.2 Remove excess water from the tile to produce a damp surface before applying the seal coat.
   3.3 Using mask described in 2.1, apply one layer of coal tar emulsion mixture with uniform thickness, flush with the mask to the tile.
   3.4 Allow the sample to cure for 96 hours at approximately 77°F and 13 to 20 percent relative humidity.
   3.5 After the curing stage, affix the brass ring to the sealer with silicon rubber.
   3.6 Fill the brass ring with kerosene and let it sit for 24 hours.
   3.7 After 24 hours, remove the kerosene and the brass ring then break the tile in half.
   3.8 Evaluate for penetration of kerosene through the sealer.
   3.9 Report the result as pass for fail.

APPENDIX B
MIX DESIGN PROCEDURE

MIX DESIGN PROCEDURE

The procedure adopted to determine optimum acceptable quantities of coal tar emulsion, water, latex, and sand makes use of a process in which trial batches with a range of formulations are prepared, then subjected to a sequence of six tests designed to eliminate the formulations not meeting test criteria. Unacceptable formulations are eliminated from further consideration.

Figure 1 outlines the process of checking a particular mix using the six steps in the process. Table B1 lists the test procedures, the associated mixture properties, and proposed criteria for each test procedure.

Steps in the Mix Design Process

There are six steps in the proposed mix design process as indicated in Figure B1. These six steps are applied to a range of materials and material quantities, emulsion, water, latex and sand, that are expected to bracket one or more acceptable mixes. It may be necessary to repeat step one in the process to find a range for any given combination of emulsion, latex and water. Once a range is established for these materials, the liquid phase of the sealer, the remaining 5 steps will lead to a selection of a final mix formulation having the desired properties.

Step 1: Perform the Brookfield viscosity test on each trial batch formulation of the liquid phase without sand; coal tar emulsion, latex additive, and water. Determine formulations that have the widest ranges for the quantities of latex and additive that meet the viscosity criteria given in Table B1.

Step 1 is designed to eliminate formulations that might have incompatible quantities of latex rubber and coal tar emulsion, that might flocculate, that have viscosities too low to suspend sand, or that would produce and unacceptable coating. Visual observations of these conditions are helpful in determining acceptable formulations within the range of viscosity values given as test criteria.

Step 2: Brookfield viscosities are next determined on acceptable trial formulations from step 1. The purpose is to identify andy new incompatibilities created by the introduction of sand, to insure that the composite material will not run off the pavement nor clog spray nozzles. This step also uses with viscosity measurements and visual observation to judge the acceptability of trial mixes. Viscosities between 10 and 90 poises are acceptable. Any mixtures not meeting this requirement will be eliminated from Step 3.

Step 3: The torque or scuff test is performed on mixes selected in Step 2. A maximum of 8 hours is allowed for setting of seal coat. An high torque value at 24 hours indicated good scuff resistance for

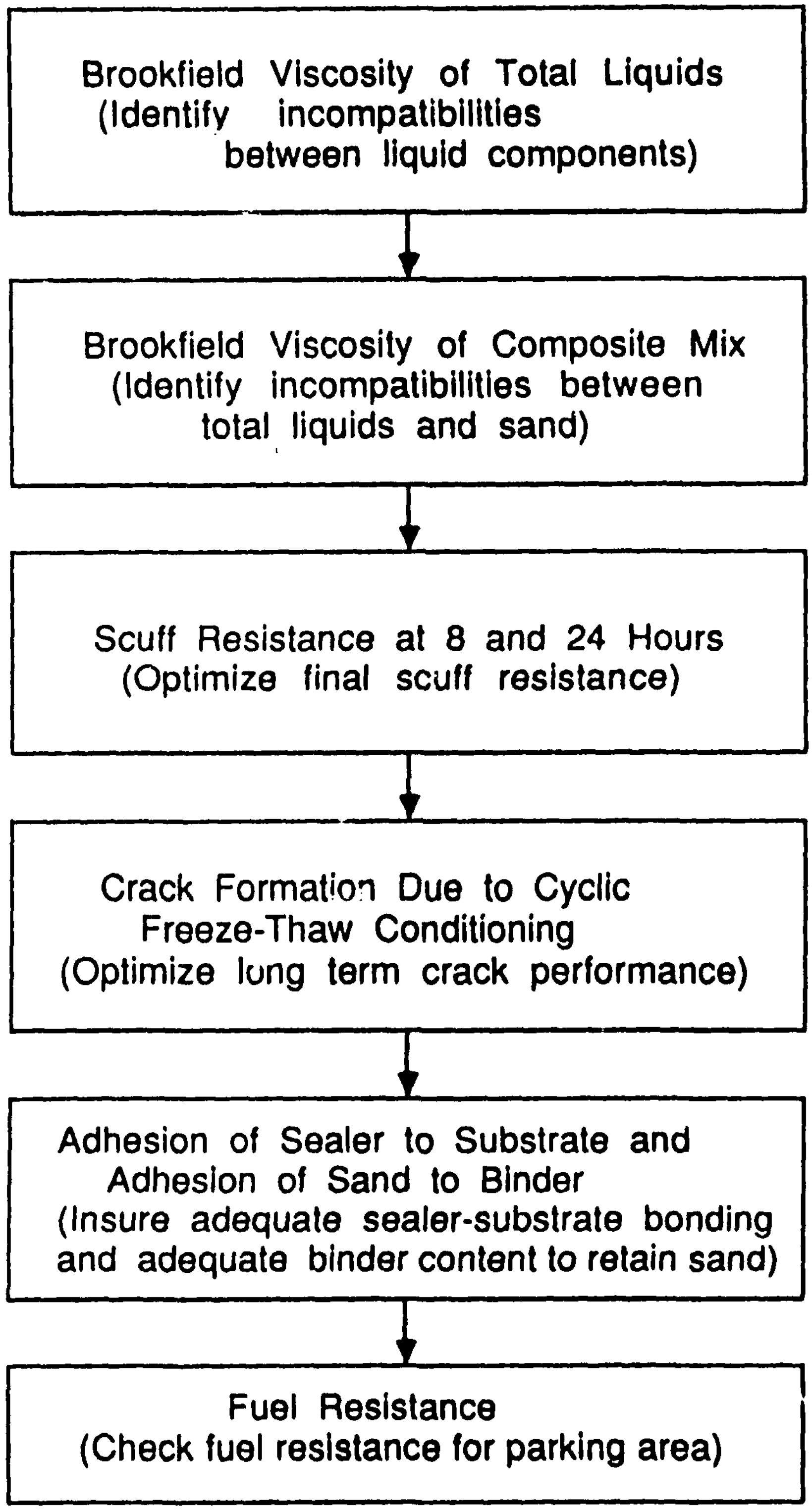


Figure B1: Determination of Optimum Component Quantities

Table B1 Proposed Test Procedures and Test Criteria

Step	Test Method	Performance Item	Criterion
1.	Brookfield Viscosity @ 77°F	Incompatibility between additive and coal tar	Viscosity between 10 and 90 poises CV = 3.7%
2.	Brookfield Viscosity @ 77°F	Workability of mix	Viscosity between 10 and 90 poises CV = 8.0%
3.	Scuff Resistance	Rate of set	8 hour torque $\geq$ 100 in-lbs
		Final Scuff resistance	24-hour torque > 8-hour torque Std Dev = 15 in-lbs
4.	Cyclic Freeze-Thaw Conditioning	Cracking	Rating $\leq$ 1 @ 5 cycles Rating $\leq$ 3 @ 10 cycles Std Dev = 0.29
5.	Tape Test	Adhesion	Rating = 5A No sand loss
6.	Tile Test	Fuel Resistance	Passes

materials used. Torque values equal to or greater than 100 in-pounds at 8 hours are acceptable. A small variation can be tolerated as long as it is within the realm of repeatability tolerances.

The results from this step have usually narrowed the acceptable combinations of components to approximately four to six. The mixture not meeting these requirements are eliminated from Step 4 test matrix.

Step 4: This step used the freeze-thaw test to check on cracking potential. Long term performance can be optimized by limiting the 5 and 10 cycle cracking in the cyclic freeze-thaw test. A rating of 1 or less at 5 cycles, and 3 or less at 10 cycles, is acceptable.

Step 5: Sand must be retained by the seal coat after it is cured, using the adhesion test as a pass-fail criteria. No sand can adhere to the tape, and no debonding of the seal coat from the test medium is allowed (adhesion rating 5A). Compositions that meet this test also should provide adequate resistance to the freeze-thaw test.

Step 6: Check the fuel resistance of the final mix.

If the sealcoat is to be used in an area where high fuel resistance is required, a "pass" rating in the fuel resistance test should be required. Mixes not meeting this criteria should be redesigned, or should be used in areas where fuel resistance is not critical.

EXAMPLE MIX DESIGN PROCEDURE

Preliminary optimum component quantities were arrived at by a process of elimination based upon the desirable limits set for each test. An example for source 2 is shown in Figure B2. This figure will be referred to as the steps are explained. Six steps for this process of eliminations are used:

Step 1: Identify incompatibilities between the components making up the liquid portion of the sealers.

Criterion:

Viscosities between 10 and 90 poises are acceptable.

Any mixtures not meeting this requirements are eliminated from the matrix for the next step. From Figure B2 it can be seen that all mixtures except the low water, low additive and the low water, medium additive are eliminated.

Step 2: Identify any new incompatibilities created by the introduction of the sand. Insure the composite material will neither run off the pavement nor clog spray bars.

Criterion:

Viscosities between 10 and 90 poises are acceptable.

Again, any mixtures not meeting this requirement are eliminated in the Step 3 matrix.

Step 3: A maximum of 8 hours was allowed for setting of seal coat. An optimum torque value at 24 hours insures the best final scuff resistance possible for the materials used.

Criterion:

Torque = or > 100 in-pounds at 8 hours
Torque = or > 8 hours value (as small difference in numbers can be tolerated as long as it is within the realm repeatability error).

The results form this step have usually narrowed the acceptable combinations of components to approximately four to six. Again, the mixtures not meeting these requirements are eliminated from the Step 4 test matrix. Figure B2 shows the 8-hours torque value in the upper left hand corner of the cell and the 24-hour cure in the lower right hand corner of the cell. It should be noted that the 8-hour torque value (85 inch-pounds) for the medium additive, low water, and low sand mixture was left in the test matrix. Any scuff test results that was within the repeatability error was given a chance to pass the remainder of the requirements.

Step 4: Determine the number of cracks developed in 5 and 10 freeze thaw cycle.

Criterion:

Rating of 1 or less at 5 cycles is required
Rating of 3 or less at 10 cycles is required

Figure B2 shows only the medium additive, low water, and high sand mixture meeting this criterion. The next step is used as a pass-fail criteria for adhesion and sand retention (ASTM D3359).

Step 5: Sand must be retained by the seal coat after it is cured.

Criterion:

No sand can adhere to the tape
No debonding of the seal coat and the test medium is allowed (adhesion rating of 5A).

The only selection that met the freeze/thaw requirement also met the adhesion/sand retention check.

Criterion:

Pass

The example passed this test.

In general, the methodology indicated the optimum combination of the range of variables investigated were for coal tar source 2: medium additive, with a low additional water, and a high sand loading.

TOTAL LIQUIDS

Step 1 - Check mix for incompatibility between coal tar and additive

		Additive			LIMITS
		Low	Med.	High	
Water	Low	29.1	30.4	4.9	Viscosity between 10 and 90 poises
	Med.	7.3	3.2	2.7	
	High	2.2	2.0	low	

COMPOSITE MIX

Step 2 - Check workability of mix

		Additive									
		Low			Medium			High			
		Water			Water			Water			
		L	M	H	L	M	H	L	M	H	Viscosity between 10 and 90 poises
Sand	L	35.1	X	X	35.6	X	X	X	X	X	
	H	60.6	X	X	43.4	X	X	X	X	X	

Step 3 - Check initial set and final scuff resistance

		Additive									
		Low			Medium			High			8 hour torque ≥ 100 in-lbs.
		Water			Water			Water			
		L	M	H	L	M	H	L	M	H	24 hour torque > 8 hour torque
Sand	L	150 110	X	X	85 120	X	X	X	X	X	
	H	150 125	X	X	100 115	X	X	X	X	X	

Step 4 - Limit crack development

		Additive									
		Low			Medium			High			Rating ≤ 1 @ 5 cycles
		Water			Water			Water			
		L	M	H	L	M	H	L	M	H	Rating ≤ 3 @ 10 cycles
Sand	L	X	X	X	3 4	X	X	X	X	X	
	H	X	X	X	0 1	X	X	X	X	X	

Step 5 - Check adhesion, between mix and substrate and between sand and binder

		Additive									
		Low			Medium			High			Adhesion rating = 5A
		Water			Water			Water			
		L	M	H	L	M	H	L	M	H	Loss of sand (Y/N)
Sand	L	X	X	X	X	X	X	X	X	X	
	H	X	X	X	5A,N	X	X	X	X	X	

Figure B2 Selection of Desirable Properties for Coal Tar Source 2 - Example

APPENDIX C
WORKABILITY TEST DATA

Additive

L = Low (4.0 gal/100 gal CT)
M = Medium (14.5 gal/100 gal CT)
H = High (25 gal/100 CT)

Water

L = Low (20 gal/100 CT)
M = Medium (55 gal/100 gal CT)
H = High (90 gal/100 gal CT)

Sand

L = Low (2 lbs/gal CT)
H = High (13 lbs/gal CT)

Table 1A : Workability Results, Phase 1 (Total Liquids)

Source	Additive	Water	Viscosity (Poise)	Residue by Evap.(%)	Density (lb/gal)
1	L	L	106.0	43.29	9.80
1	L	M	35.2	33.81	9.49
1	L	H	11.0	28.44	9.23
1	M	L	(a)	43.30	9.50
1	M	M	37.4	33.33	9.21
1	M	H	20.0	34.16	9.32
1	H	L	(a)	(a)	(a)
1	H	M	29.4	33.66	8.99
1	H	H	15.8	34.09	9.13
2	L	L	26.0	44.07	10.01
2	L	M	4.0	37.30	9.51
2	L	H	(b)	28.76	9.23
2	M	L	27.6	41.90	9.84
2	M	M	8.9	35.85	9.55
2	M	H	4.0	29.00	9.33
2	H	L	26.4	44.73	9.13
2	H	M	6.0	33.46	9.37
2	H	H	4.3	28.76	9.25
3	L	L	71.4	42.87	9.91
3	L	M	41.0	35.17	9.57
3	L	H	7.5	27.93	9.26
3	M	L	4.9	41.60	9.66
3	M	M	3.9	35.12	9.40
3	M	H	4.3	34.17	9.44
3	H	L	1.9	42.66	9.68
3	H	M	(b)	30.65	9.14
3	H	H	(b)	28.81	8.46
4	L	L	119.0	41.27	9.28
4	L	M	51.2	32.18	9.45
4	L	H	6.0	27.93	9.42
4	M	L	134.0	38.95	9.46
4	M	M	87.6	33.27	9.09
4	M	H	6.6	27.32	9.16
4	H	L	146.0	42.96	9.42
4	H	M	24.4	35.06	9.36
4	H	H	7.5	29.49	9.25
5	L	L	186.0	42.81	9.87
5	L	M	73.3	35.44	9.51
5	L	H	57.8	29.03	9.29
5	M	L	326.0	42.94	9.44
5	M	M	52.6	34.15	9.26
5	M	H	3.7	29.22	9.26
5	H	L	6.6	43.24	9.61
5	H	M	1.6	33.20	9.35
5	H	H	2.7	29.18	9.26

(a) - Too thick to test
(b) - Too thin to test

Table 2A : Workability Results, Phase 1 (Composite System)

Source	Additive	Water	Sand	Sand Type (R,A)	Sand Grad (F,C)	Viscosity (Poise)
1	H	H	L	A	C	28.0
1	H	H	L	R	F	28.0
1	H	H	H	A	F	38.0
1	H	H	H	R	C	44.4
1	L	L	L	A	C	102.0
1	L	L	L	R	F	103.0
1	L	L	H	A	F	137.0
1	L	L	H	R	C	138.0
1	H	L	H	A	C	(a)
1	H	L	H	R	F	(a)
1	H	L	L	A	F	(a)
1	H	L	L	R	C	(a)
1	L	H	H	R	F	28.0
1	L	H	H	A	C	13.8
1	L	H	L	R	C	6.3
1	L	H	L	A	F	7.4
2	H	H	L	A	C	3.8
2	H	H	L	R	F	4.4
2	H	H	H	A	F	6.4
2	H	H	H	R	C	7.4
2	L	L	L	A	C	28.8
2	L	L	L	R	F	23.6
2	L	L	H	A	F	48.8
2	L	L	H	R	C	34.8
2	H	L	H	A	C	38.0
2	H	L	H	R	F	40.4
2	H	L	L	A	F	24.2
2	H	L	L	R	C	29.2
2	L	H	H	R	F	(b)
2	L	H	H	A	C	(b)
2	L	H	L	R	C	(b)
2	L	H	L	A	F	(b)
3	H	H	L	A	C	(b)
3	H	H	L	R	F	(b)
3	H	H	H	A	F	4.5
3	H	H	H	R	C	3.4
3	L	L	L	A	C	72.0
3	L	L	L	R	F	72.6
3	L	L	H	A	F	114.0
3	L	L	H	R	C	108.0
3	H	L	H	A	C	137.0
3	H	L	H	R	F	100.0
3	H	L	L	A	F	38.8
3	H	L	L	R	C	51.6
3	L	H	H	R	F	38.0
3	L	H	H	A	C	37.0
3	L	H	L	R	C	21.8
3	L	H	L	A	F	22.8

Table 2A : Workability Results, Phase 1 (Composite System) (Continued)

Source	Additive	Water	Sand	Sand Type (R,A)	Sand Grad (F,C)	Viscosity (Poise)
4	H	H	L	A	C	21.0
4	H	H	L	R	F	20.0
4	H	H	H	A	F	66.2
4	H	H	H	R	C	54.3
4	L	L	L	A	C	94.0
4	L	L	L	R	F	90.0
4	L	L	H	A	F	130.0
4	L	L	H	R	C	150.0
4	H	L	H	A	C	(a)
4	H	L	H	R	F	(a)
4	H	L	L	A	F	304.0
4	H	L	L	R	C	234.0
4	L	H	H	R	F	38.0
4	L	H	H	A	C	33.2
4	L	H	L	R	C	32.4
4	L	H	L	A	F	39.6
5	H	H	L	A	C	3.4
5	H	H	L	R	F	2.0
5	H	H	H	A	F	4.9
5	H	H	H	R	C	3.6
5	L	L	L	A	C	163.0
5	L	L	L	R	F	163.0
5	L	L	H	A	F	160.0
5	L	L	H	R	C	173.0
5	H	L	H	A	C	123.0
5	H	L	H	R	F	84.0
5	H	L	L	A	F	25.4
5	H	L	L	R	C	30.8
5	L	H	H	R	F	54.2
5	L	H	H	A	C	40.2
5	L	H	L	R	C	25.2
5	L	H	L	A	F	26.8

Sand
- L = Low (2.0lbs/gal CT)
- H = High (13lbs/gal CT)
- R = Round
- A = Angular
- F = Fine
- C = Coarse

(a) - Too thick to test
(b) - Too thin to test

Table 3A: Workability Results, Phase 2 (Total Liquids)

Source	Additive	Water	Viscosity** (Poise)	Settling** final/ intial
1	L	L	114.5	3.9
1	L	M	8.2	10.5
1	L	H	3.8	8
1	M	L	59.6	0.6
1	M	M	15.4	9.6
1	M	H	29.2	13.3
1	H	L	(a)	(a)
1	H	M	(a)	(a)
1	H	H	(a)	(a)
2	L	L	29.1	1.8
2	L	M	7.3	14.7
2	L	H	2.2	16.2
2	M	L	30.4	1.8
2	M	M	3.8	14.4
2	M	H	2.0	5.6
2	H	L	4.9	27.7
2	H	M	2.7	36.0
2	H	H	(b)	(b)
3	L	L	106.5	2.6
3	L	M	43.7	4.4
3	L	H	21.2	2.5
3	M	L	105.5	Max
3	M	M	27.6	88.0
3	M	H	7.8	11.5
3	H	L	20.6	77.6
3	H	M	(b)	(b)
3	H	H	(b)	(b)
4	L	L	31.5	0.3
4	L	M	23.3	0.6
4	L	H	14.1	2.0
4	M	L	160.0	MAX
4	M	M	26.6	MAX
4	M	H	26.2	MAX
4	H	L	40.4	MAX
4	H	M	32.7	MAX
4	H	H	11.2	18.3
6	L	L	(a)	(a)
6	L	M	67.0	MAX
6	L	H	21.2	9.9
6	M	L	(a)	(a)
6	M	M	42.0	MAX
6	M	H	6.6	77.2
6	H	L	(a)	(a)
6	H	M	26.8	40.3
6	H	H	(b)	(b)

(a) - Too thick to test
(b) - Too thin to test
** - Values are an average of two readings

Table 4A: Workability Results, Phase 2 (Composite Mix)

Source	Additive	Water	Sand	Viscosity (Poise)	Settling final/ intial
1	L	L	L	125	8.0
1	L	M	L	9.0	7.9
1	L	H	L	3.4	18.9
1	L	L	H	188	MAX
1	L	M	H	17.3	30.0
1	L	H	H	5.0	10.2
1	M	L	L	44.6	1.8
1	M	M	L	11.1	57.1
1	M	H	L	29.2	4.9
1	M	L	H	130	(a)
1	M	M	H	33.2	MAX
1	M	H	H	16.6	MAX
1	H	L	L	(a)	(a)
1	H	M	L	(a)	(a)
1	H	H	L	(a)	(a)
1	H	L	H	(a)	(a)
1	H	M	H	(a)	(a)
1	H	H	H	(a)	(a)
2	L	L	L	31.5	MAX
2	L	M	L	7.3	10.2
2	L	H	L	(b)	22.1
2	L	L	H	60.6	MAX
2	L	M	H	12.0	MAX
2	L	H	H	3.1	36.4
2	M	L	L	35.6	MAX
2	M	M	L	5.5	27.2
2	M	H	L	1.9	2.33
2	M	L	H	43.4	MAX
2	M	M	H	6.7	312.0
2	M	H	H	1.8	4.1
2	H	L	L	5.3	19.6
2	H	M	L	2.8	29.2
2	H	H	L	(b)	(b)
2	H	L	H	15.0	MAX
2	H	M	H	5.3	125.5
2	H	H	H	(b)	(b)

Table 4A: Workability Results, Phase 2 (Composite Mix) (Continued)

Source	Additive	Water	Sand	Viscosity (Poise)	Settling final/ intial
3	L	L	L	100	9.9
3	L	M	L	44.4	7.2
3	L	H	L	18.4	3.8
3	L	L	H	172	MAX
3	L	M	H	54.0	MAX
3	L	H	H	24.2	MAX
3	M	L	L	124	MAX
3	M	M	L	45.2	MAX
3	M	H	L	23.0	16.8
3	M	L	H	(a)	(a)
3	M	M	H	86.6	MAX
3	M	H	H	34.4	MAX
3	H	L	L	51.4	15.2
3	H	M	L	(b)	(b)
3	H	H	L	(b)	(b)
3	H	L	H	87.6	MAX
3	H	M	H	(b)	(b)
3	H	H	H	(b)	(b)
4	L	L	L	30.8	0.8
4	L	M	L	13.6	5.9
4	L	H	L	12.4	9.5
4	L	L	H	76.8	MAX
4	L	M	H	26.2	MAX
4	L	H	H	19.7	MAX
4	M	L	L	102.0	0.8
4	M	M	L	60.8	MAX
4	M	H	L	52.6	MAX
4	M	L	H	189.0	MAX
4	M	M	H	208.0	MAX
4	M	H	H	76.4	MAX
4	H	L	L	206.0	MAX
4	H	M	L	69.8	MAX
4	H	H	L	30.2	MAX
4	H	L	H	(a)	(a)
4	H	M	H	119.0	MAX
4	H	H	H	35.6	MAX

Table 4A: Workability Results, Phase 2 (Composite Mix) (Continued)

Source	Additive	Water	Sand	Viscosity (Poise)	Settling final/ intial
6	L	L	L	(a)	(a)
6	L	M	L	86.4	MAX
6	L	H	L	36.0	MAX
6	L	L	H	(a)	(a)
6	L	M	H	92.2	MAX
6	L	H	H	60.2	MAX
6	M	L	L	(a)	(a)
6	M	M	L	87.0	MAX
6	M	H	L	47.6	MAX
6	M	L	H	(a)	(a)
6	M	M	H	(a)	(a)
6	M	H	H	33.8	MAX
6	H	L	L	(a)	(a)
6	H	M	L	64.4	MAX
6	H	H	L	(b)	(b)
6	H	L	H	(a)	(a)
6	H	M	H	123.0	MAX
6	H	H	H	(b)	(b)

(a) - Too thick to test
(b) - Too thin to test
\+ - Sand removal by tape
Max - Unable to rotate paddle with maximum weight

APPENDIX D
SCUFF TEST DATA

Additive

L = Low (4.0 gal/100 gal CT)
M = Medium (14.5 gal/100 gal CT)
H = High (25 gal/100 CT)

Water

L = Low (20 gal/100 CT)
M = Medium (55 gal/100 gal CT)
H = High (90 gal/100 gal CT)

Sand

L = Low (2 lbs/gal CT)
H = High (13 lbs/gal CT)

Table 1B: Scuff Test Results, Phase 1

Source	Additive	Water	Sand	Sand Type (R,A)	Sand Grad (F,C)	Cure Time (hours) 1	2	3	4	24
						Torque (in.-lbs)				
1	H	H	L	A	C	80	75	80	150*	135
1	H	H	L	R	F	85	75	110	125	140
1	H	H	H	A	F	65	60	70	130	140
1	H	H	H	R	C	53	55	145	150*	133
1	L	L	L	A	C	60	75	75	65	148
1	L	L	L	R	F	110	75	70	80	143
1	L	L	H	A	F	65	45	65	65	150*
1	L	L	H	R	C	40	45	75	100	150
1	H	L	H	A	C	(a)	(a)	(a)	(a)	(a)
1	H	L	H	R	F	(a)	(a)	(a)	(a)	(a)
1	H	L	L	A	F	(a)	(a)	(a)	(a)	(a)
1	H	L	L	R	C	(a)	(a)	(a)	(a)	(a)
1	L	H	H	R	F	100	80	75	75	140
1	L	H	H	A	C	75	65	60	75	150*
1	L	H	L	R	C	140	120	100	125	150
1	L	H	L	A	F	125	125	120	135	150*
2	H	H	L	A	C	125	85	110	120	130
2	H	H	L	R	F	135	105	150*	87	120
2	H	H	H	A	F	75	135	135	110	130
2	H	H	H	R	C	90	75	150*	150*	120
2	L	L	L	A	C	120	80	90	75	150*
2	L	L	L	R	F	100	90	75	75	145
2	L	L	H	A	F	60	100	150*	150*	150*
2	L	L	H	R	C	55	70	90	130	150*
2	H	L	H	A	C	52	50	90	80	150*
2	H	L	H	R	F	65	55	60	150	150
2	H	L	L	A	F	105	95	85	120	130
2	H	L	L	R	C	110	100	125	125	125
2	L	H	H	R	F	(b)	(b)	(b)	(b)	(b)
2	L	H	H	A	C	(b)	(b)	(b)	(b)	(b)
2	L	H	L	R	C	(b)	(b)	(b)	(b)	(b)
2	L	H	L	A	F	(b)	(b)	(b)	(b)	(b)
3	H	H	L	A	C	(b)	(b)	(b)	(b)	(b)
3	H	H	L	R	F	(b)	(b)	(b)	(b)	(b)
3	H	H	H	A	F	(b)	(b)	(b)	(b)	(b)
3	H	H	H	R	C	(b)	(b)	(b)	(b)	(b)
3	L	L	L	A	C	65	80	85	120	145
3	L	L	L	R	F	60	70	75	135	130
3	L	L	H	A	F	55	80	150*	150	150*
3	L	L	H	R	C	50	85	150*	150*	150*
3	H	L	H	A	C	55	70	75	150*	150*
3	H	L	H	R	F	60	85	150*	150*	150*
3	H	L	L	A	F	130	105	125	150	150*
3	H	L	L	R	C	90	80	110	125	150*
3	L	H	H	R	F	87	70	120	75	150*
3	L	H	H	A	C	70	68	68	135	150*
3	L	H	L	R	C	115	100	125	80	150*
3	L	H	L	A	F	120	103	80	75	135

Table 1B: Scuff Test Results, Phase 1
(Continued)

Source	Additive	Water	Sand	Sand Type (R,A)	Sand Grad (F,C)	Cure Time (hours) 1	2	3	4	24
						Torque (in.-lbs)				
4	H	H	L	A	C	135	115	125	115	150*
4	H	H	L	R	F	135	115	120	115	150*
4	H	H	H	A	F	110	90	90	87	150*
4	H	H	H	R	C	90	80	80	115	150*
4	L	L	L	A	C	110	110	90	95	150*
4	L	L	L	R	F	105	130	90	80	150*
4	L	L	H	A	F	70	60	95	115	150
4	L	L	H	R	C	60	55	80	140	150*
4	H	L	H	A	C	(a)	(a)	(a)	(a)	(a)
4	H	L	H	R	F	(a)	(a)	(a)	(a)	(a)
4	H	L	L	A	F	(a)	(a)	(a)	(a)	(a)
4	H	L	L	R	C	(a)	(a)	(a)	(a)	(a)
4	L	H	H	R	F	70	75	140	135	145
4	L	H	H	A	C	75	55	75	135	150*
4	L	H	L	R	C	100	95	90	110	150*
4	L	H	L	A	F	120	105	97	105	150
5	H	H	L	A	C	(b)	(b)	(b)	(b)	(b)
5	H	H	L	R	F	(b)	(b)	(b)	(b)	(b)
5	H	H	H	A	F	(b)	(b)	(b)	(b)	(b)
5	H	H	H	R	C	(b)	(b)	(b)	(b)	(b)
5	L	L	L	A	C	60	95	90	95	150*
5	L	L	L	R	F	75	110	90	100	150*
5	L	L	H	A	F	60	63	60	65	150*
5	L	L	H	R	C	50	50	60	60	150*
5	H	L	H	A	C	83	85	110	150*	150*
5	H	L	H	R	F	98	100	140	150	150*
5	H	L	L	A	F	118	110	80	100	150*
5	H	L	L	R	C	110	100	95	140	150*
5	L	H	H	R	F	100	80	87	88	145
5	L	H	H	A	C	110	75	78	75	140
5	L	H	L	R	C	130	108	100	85	150
5	L	H	L	A	F	120	108	110	85	148

Sand
- L = Low (2.0lbs/gal CT)
- H = High (13lbs/gal CT)
- R = Round
- A = Angular
- F = Fine
- C = Coarse

(a) - Too thick to test
(b) - Too thin to test
* - Maximum torque reading

Table 2B: Scuff Test Results, Phase 2

Source	Additive	Water	Sand	Cure Time (hours) 1	2	3	4	8	24
				Torque (in.-lbs.)					
1	L	L	L	100	85	75	90	100	160
1	L	M	L	95	135	130	100	100	135
1	L	H	L	140	135	80	75	100	100
1	L	L	H	75	70	75	65	50	225
1	L	M	H	85	65	85	130	130	165
1	L	H	H	(b)	(b)	(b)	(b)	(b)	(b)
1	M	L	L	80	115	100	100	145	140
1	M	M	L	110	85	105	75	80	145
1	M	H	L	110	90	75	75	90	120
1	M	L	H	60	55	35	100	150	175
1	M	M	H	75	95	95	115	150	205
1	M	H	H	40	55	70	120	150	130
1	H	L	L	(a)	(a)	(a)	(a)	(a)	(a)
1	H	M	L	(a)	(a)	(a)	(a)	(a)	(a)
1	H	H	L	(a)	(a)	(a)	(a)	(a)	(a)
1	H	L	H	(a)	(a)	(a)	(a)	(a)	(a)
1	H	M	H	(a)	(a)	(a)	(a)	(a)	(a)
1	H	H	H	(a)	(a)	(a)	(a)	(a)	(a)
2	L	L	L	115	75	100	75	150	110
2	L	M	L	85	75	60	105	125	190
2	L	H	L	120	65	40	50	50	135
2	L	L	H	65	40	35	70	150	125
2	L	M	H	35	55	50	80	100	170
2	L	H	H	75	40	40	40	150	175
2	M	L	L	65	100	75	60	85	120
2	M	M	L	95	80	45	80	75	75
2	M	H	L	100	110	115	95	90	120
2	M	L	H	45	40	40	120	100	115
2	M	M	H	60	75	100	150	225	175
2	M	H	H	70	90	70	105	165	150
2	H	L	L	85	65	65	70	70	170
2	H	M	L	60	75	25	55	120	115
2	H	H	L	(b)	(b)	(b)	(b)	(b)	(b)
2	H	L	H	40	55	50	30	95	180
2	H	M	H	65	60	20	50	155	200
2	H	H	H	(b)	(b)	(b)	(b)	(b)	(b)

Table 2B: Scuff Test Results, Phase 2
(Continued)

Source	Additive	Water	Sand	Cure Time (hours) 1	2	3	4	8	24
				Torque (in.-lbs.)					
3	L	L	L	90	55	55	50	95	100
3	L	M	L	100	90	90	80	95	100
3	L	H	L	65	40	30	45	70	135
3	L	L	H	55	65	85	140	115	300
3	L	M	H	20	25	25	50	100	95
3	L	H	H	20	20	25	50	100	120
3	M	L	L	60	60	75	100	115	130
3	M	M	L	50	55	55	55	65	60
3	M	H	L	70	95	90	80	70	155
3	M	L	H	(b)	(b)	(b)	(b)	(b)	(b)
3	M	M	H	40	30	30	25	60	75
3	M	H	H	75	90	45	60	155	140
3	H	L	L	55	80	70	50	120	125
3	H	M	L	(b)	(b)	(b)	(b)	(b)	(b)
3	H	H	L	(b)	(b)	(b)	(b)	(b)	(b)
3	H	L	H	45	40	35	55	120	130
3	H	M	H	(b)	(b)	(b)	(b)	(b)	(b)
3	H	H	H	(b)	(b)	(b)	(b)	(b)	(b)
4	L	L	L	50	65	50	65	155	145
4	L	M	L	125	65	50	50	105	115
4	L	H	L	105	85	90	115	110	150
4	L	L	H	35	45	35	65	145	150
4	L	M	H	50	30	25	50	100	105
4	L	H	H	60	45	80	110	130	155
4	M	L	L	60	40	45	70	105	120
4	M	M	L	75	50	45	40	115	140
4	M	H	L	75	80	80	125	140	140
4	M	L	H	25	35	40	80	150	225
4	M	M	H	30	30	35	85	80	75
4	M	H	H	60	70	45	155	175	160
4	H	L	L	60	55	50	95	120	110
4	H	M	L	30	40	40	100	80	125
4	H	H	L	105	110	95	60	110	175
4	H	L	H	(a)	(a)	(a)	(a)	(a)	(a)
4	H	M	H	25	35	40	100	150	190
4	H	H	H	60	60	50	50	140	130

Table 2B: Scuff Test Results, Phase 2
(Continued)

Source	Additive	Water	Sand	Cure Time (hours) 1	2	3	4	8	24
				Torque (in.-lbs.)					
6	L	L	L	(a)	(a)	(a)	(a)	(a)	(a)
6	L	M	L	80	60	80	70	150	150
6	L	H	L	75	80	85	75	85	125
6	L	L	H	(a)	(a)	(a)	(a)	(a)	(a)
6	L	M	H	50	50	60	50	225	200
6	L	H	H	65	60	50	50	55	185
6	M	L	L	(a)	(a)	(a)	(a)	(a)	(a)
6	M	M	L	105	75	70	90	200	150
6	M	H	L	80	75	100	80	100	105
6	M	L	H	(a)	(a)	(a)	(a)	(a)	(a)
6	M	M	H	(a)	(a)	(a)	(a)	(a)	(a)
6	M	H	H	50	40	60	75	140	130
6	H	L	L	(a)	(a)	(a)	(a)	(a)	(a)
6	H	M	L	90	95	65	110	145	135
6	H	H	L	(b)	(b)	(b)	(b)	(b)	(b)
6	H	L	H	(a)	(a)	(a)	(a)	(a)	(a)
6	H	M	H	60	60	50	150	185	180
6	H	H	H	(b)	(b)	(b)	(b)	(b)	(b)

(a) - Too thick to test
(b) - Too thin to test

APPENDIX E
CRACKING DATA

Additive

L = Low (4.0 gal/100 gal CT)
M = Medium (14.5 gal/100 gal CT)
H = High (25 gal/100 CT)

Water

L = Low (20 gal/100 CT)
M = Medium (55 gal/100 gal CT)
H = High (90 gal/100 gal CT)

Sand

L = Low (2 lbs/gal CT)
H = High (13 lbs/gal CT)

Table 1C: Field Test Section Cracking

Time (Mo)

Field Test Section	Oct 86	Nov 86	Dec 86	Jan 87	Feb 87	Mar 87	Apr 87	May 87	Jun 87	Jul 87	Aug 87	Sep 87	Oct 87	Nov 87	Dec 87	Jan 88	Feb 88	Mar 88	Apr 88	May 88	Jun 88	Jul 88	Aug 88
1	0	1	1	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3.5
2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2	2.5
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2
8 with top coat	0	1	1	1	1	1	1	2	2	3	3	3	4	4	4	4	4	4	4	4	4	4	4
8 with out top coat	0	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3.5	.3.5	4	4	4	4
9 with top coat	0	1	1	1	1	1	2	2	2	3	3	3	3	4	4	4	4	4	4	4	4	4	4
9 with out top coat	0	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3
12	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3.5
13	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3.5
14	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3.5
15	0	0	0	0	0	0	0	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3.5
16	0	0	0	0	0	0	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	4
17	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3.5

0 = no cracking
1 = hairline cracking
2 = slight cracking
3 = moderate cracking
4 = severe cracking

Table 2C: Cyclic Freeze/ Thaw Conditioning Results

	CYCLE														
Sample Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	1	1	1	1	1	1.5	1.5	1.5	2	2
1	0	0	0	0	0	1	1	1.5	2	2	2	2	2	2	2
1	0	0	1	1	1	1	1.5	2	2	2	2.5	3	3	3	3.5
1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
1	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
1	0	0	0	0	0	0	0	0	1	1	1	1	1	1.5	2
1	0	0	0	0	0	0	0	0	0	0	0	0.5	1	1	1
1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
1	0	0	0	0	0	0	0	0	1	1	1	1	1.5	2	2
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
1	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
1	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
1	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
1	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
1	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	0	1	1	1.5	2	2	2	2	2.5	3	3	3	3	3.5	3.5
2	0	1	1	1.5	2	2	2	2	2	2	2	2	2	2	2.5
2	0+	1	1	2	2	2	2	2.5	2.5	2.5	2.5	2.5	2.5	3	3
2	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0.5	1	1
2	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
2	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
2	0+	2.5	2.5	3	3	4	4	4	4	4	4	4	4	4	4
2	1+	1.5	2	2	3	3	3	3	3	3.5	4	4	4	4	4
2	0	1	1.5	2	2	2	2	3	3	3.5	4+	4+	4+	4+	4+
2	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
2	0	0	0	0	1	1	1	1.5	2	2	2	2	2	2	2
2	0+	1	1	2	2	2.5	3	3	3.5	3.5	4	4	4	4	4
2	0+	0	1	1	1.5	1.5	2	2	3	3	3	3	3	3	3
2	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0+	0	0	0	0	0	0	0	1	1	1	1	1	1	1
2	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)

Table 2C: Cyclic Freeze/ Thaw Conditioning Results
(Continued)

Sample Number	CYCLE 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
3	0	0	0	1	1	1	1	1	1	1	1	1	1	1.5	2
3	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
3	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
3	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
3	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
3	0+	0	0	0	0	0	1	1	1	1	2	2	2	2	2
3	0+	0	1	2	2	2	2.5	2.5	2.5	3	3	3	3	4	4
3	0+	0	1	1.5	1.5	2	2	2	2	2	2	2	3	3	3
3	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
3	0	0	1	1	1	1	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
3	0+	0	1	1	1	2	2	2	2	2	2	2	2	3	3
3	0+	0	0	0	1	1	1	1	1	2	2	2	2	2	2
3	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
3	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
3	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
3	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
3	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
4	0	0.5	1	1	1	1.5	2	2	2	2	2	2	2	2	2
4	1+	1.5	2	2	2	2	2	2.5	3	3	3	3	3	3	3
4	0+	0	1	1	1	1	1	1	1	1	2	2	2	2	2
4	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
4	0	0	0.5	0.5	1	1	1	1	1	1	1	1	1	1	1
4	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
4	0	0	0.5	0.5	1	1	2	2	2	2	2	2	2	2	2
4	0+	0	1	1	1	1	1	1	2	2	2	2	2.5	2.5	2.5
4	0+	0	1	1	1	1	1.5	2	2	2	2	2	2	3	3
4	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
4	0+	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	0+	1	1	1	1	1	1	1	1	2	2	3	3	3	3
4	0+	0	1	1.5	1.5	2	2	2.5	2.5	2.5	3	3	3	3	3
4	0+	0	0	1	1	1	1	2	2	2	3	3	3	3	3
4	0+	1	1	1.5	2	3	3.5	3.5	4	4	4	4	4	4	4
4	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
4	1+	1	1	1	1	1	1	1	1	1	1	1	2	2	2
4	0+	1	1	1	1	2	2	2	2	2	2	2	2	3	3

Table 2C: Cyclic Freeze/ Thaw Conditioning Results (Continued)

Sample Number	CYCLE 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	0	1	1	1	1	2	2	2	3	3	3	3	4	4	4
6	0	1	1	1	1	1	1	2	2	2	2.5	2.5	3	3	3
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2
6	0+	0	0	0	1	1	1	1	1	1	1	1	1	1	1
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	0+	0	0	1	1	1	2	2	2	3	3	3	3	3	3
6	1+	2	2	3	3	3	3	4	4	4	4	4	4	4	4
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	1+	2	2	3	3	3	3	4	4	4	4	4	4	4	4
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	0+	1	1	2	3	4	4	4	4	4	4	4	4	4	4
6	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
6	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)

(a) - Too thick to test
(b) - Too thin to test
+ - drying shrinkage
0 - no cracking
1 - hairline cracking
2 - slight cracking
3 - moderate cracking
4 - severe cracking

Table 2C: Cyclic Freeze/ Thaw Conditioning Results (Continued)

Sample Number	CYCLE 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	0	1	1	1	1	2	2	2	3	3	3	3	4	4	4
6	0	1	1	1	1	1	1	2	2	2	2.5	2.5	3	3	3
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2
6	0+	0	0	0	1	1	1	1	1	1	1	1	1	1	1
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	0+	0	0	1	1	1	2	2	2	3	3	3	3	3	3
6	1+	2	2	3	3	3	3	4	4	4	4	4	4	4	4
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	1+	2	2	3	3	3	3	4	4	4	4	4	4	4	4
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	0+	1	1	2	3	4	4	4	4	4	4	4	4	4	4
6	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
6	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
6	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2
6	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)

(a) - Too thick to test
(b) - Too thin to test
+ - drying shrinkage
0 - no cracking
1 - hairline cracking
2 - slight cracking
3 - moderate cracking
4 - severe cracking

Table 3C: Flexibility Results, Phase 1 (Total Liquids)

Source	Additive	Water	Flex. ** Rating
1	L	L	1*
1	L	M	2*
1	L	H	1*
1	M	L	0
1	M	M	0
1	M	H	1*
1	H	L	(a)
1	H	M	0
1	H	H	(a)
2	L	L	2
2	L	M	(b)
2	L	H	(b)
2	M	L	0+
2	M	M	0+
2	M	H	(b)
2	H	L	0+
2	H	M	1+
2	H	H	(b)
3	L	L	0+
3	L	M	0+
3	L	H	0+
3	M	L	0
3	M	M	0
3	M	H	0
3	H	L	0
3	H	M	(b)
3	H	H	(b)

Table 3C: Flexibility Results, Phase 1 (Total Liquids) (Continued)

Source	Additive	Water	Flex. ** Rating
4	L	L	1+
4	L	M	1
4	L	H	1*
4	M	L	1*
4	M	M	1
4	M	H	1*
4	H	L	0
4	H	M	0
4	H	H	1
5	L	L	(c)
5	L	M	1+
5	L	H	(c)
5	M	L	0
5	M	M	0
5	M	H	0
5	H	L	(a)
5	H	M	0
5	H	H	(c)

(a) - Too thick to test
(b) - Too thin to test
(c) - Unable to complete tests due to shortage of material
* - Material released from panal
** - Flexibility Rating
0 = no visible metal beneath cracks
1 = one to two cracks
2 = three to four cracks
3 = five to six cracks
4 = seven to eight cracks
5 = nine to ten cracks
\+ = material displayed hairline cracking

Table 4C: Flexibility Results, Phase 1 (Composite System)

Source	Additive	Water	Sand	Sand Type (R,A)	Sand Grad (F,C)	Flex.** Rat.
1	H	H	L	A	C	(a)
1	H	H	L	R	F	(a)
1	H	H	H	A	F	(a)
1	H	H	H	R	C	(a)
1	L	L	L	A	C	1*
1	L	L	L	R	F	1*
1	L	L	H	A	F	1
1	L	L	H	R	C	1*
1	H	L	H	A	C	(a)
1	H	L	H	R	F	(a)
1	H	L	L	A	F	(a)
1	H	L	L	R	C	(a)
1	L	H	H	R	F	0+
1	L	H	H	A	C	0+
1	L	H	L	R	C	0
1	L	H	L	A	F	0
2	H	H	L	A	C	(b)
2	H	H	L	R	F	(b)
2	H	H	H	A	F	(b)
2	H	H	H	R	C	(b)
2	L	L	L	A	C	1
2	L	L	L	R	F	2
2	L	L	H	A	F	1
2	L	L	H	R	C	1
2	H	L	H	A	C	0+
2	H	L	H	R	F	0+
2	H	L	L	A	F	1+
2	H	L	L	R	C	1+
2	L	H	H	R	F	(b)
2	L	H	H	A	C	(b)
2	L	H	L	R	C	(b)
2	L	H	L	A	F	(b)

Table 4C: Flexibility Results, Phase 1 (Composite System) (Continued)

Source	Additive	Water	Sand	Sand Type (R,A)	Sand Grad (F,C)	Flex.** Rat.
3	H	H	L	A	C	(b)
3	H	H	L	R	F	(b)
3	H	H	H	A	F	(b)
3	H	H	H	R	C	(b)
3	L	L	L	A	C	0+
3	L	L	L	R	F	0+
3	L	L	H	A	F	0+
3	L	L	H	R	C	0+
3	H	L	H	A	C	0+
3	H	L	H	R	F	0+
3	H	L	L	A	F	0
3	H	L	L	R	C	0
3	L	H	H	R	F	0+
3	L	H	H	A	C	0+
3	L	H	L	R	C	0
3	L	H	L	A	F	0+
4	H	H	L	A	C	1
4	H	H	L	R	F	0
4	H	H	H	A	F	0
4	H	H	H	R	C	0
4	L	L	L	A	C	1*+
4	L	L	L	R	F	1+
4	L	L	H	A	F	0+
4	L	L	H	R	C	0+
4	H	L	H	A	C	(a)
4	H	L	H	R	F	(a)
4	H	L	L	A	F	(a)
4	H	L	L	R	C	(a)
4	L	H	H	R	F	0+
4	L	H	H	A	C	0
4	L	H	L	R	C	1*
4	L	H	L	A	F	1*

Table 4C: Flexibility Results, Phase 1 (Composite System) (Continued)

Source	Additive	Water	Sand	Sand Type (R,A)	Sand Grad (F,C)	Flex.** Rat.
5	H	H	L	A	C	(b)
5	H	H	L	R	F	(b)
5	H	H	H	A	F	(b)
5	H	H	H	R	C	(b)
5	L	L	L	A	C	1+
5	L	L	L	R	F	0+
5	L	L	H	A	F	0+
5	L	L	H	R	C	0+
5	H	L	H	A	C	0+
5	H	L	H	R	F	0+
5	H	L	L	A	F	2*
5	H	L	L	R	C	1*
5	L	H	H	R	F	0+
5	L	H	H	A	C	0+
5	L	H	L	R	C	0
5	L	H	L	A	F	0+

(a) - Too thick to test
(b) - Too thin to test
* - Material released from panal
+ - Material displayed hairline cracking
** - Flexibility rating same as before

APPENDIX F
ADHESION TEST DATA

Additive

L = Low (4.0 gal/100 gal CT)
M = Medium (14.5 gal/100 gal CT)
H = High (25 gal/100 CT)

Water

L = Low (20 gal/100 CT)
M = Medium (55 gal/100 gal CT)
H = High (90 gal/100 gal CT)

Sand

L = Low (2 lbs/gal CT)
H = High (13 lbs/gal CT)

Table 1D: Results of Adhesion testing, Phase 2 (Total Liquids)

Sample Number	Additive	Water	Adhesion *** Rating
1	L	L	5A
1	L	M	5A
1	L	H	5A
1	M	L	5A
1	M	M	5A
1	M	H	5A
1	H	L	(a)
1	H	M	(a)
1	H	H	(a)
2	L	L	5A
2	L	M	5A
2	L	H	5A
2	M	L	5A
2	M	M	5A
2	M	H	5A
2	H	L	5A
2	H	M	5A
2	H	H	(b)
3	L	L	5A
3	L	M	5A
3	L	H	5A
3	M	L	5A
3	M	M	5A
3	M	H	5A
3	H	L	5A
3	H	M	(b)
3	H	H	(b)

Table 1D: Results of Adhesion testing, Phase 2 (Total Liquids) (Continued)

Sample Number	Additive	Water	Adhesion *** Rating
4	L	L	5A
4	L	M	5A
4	L	H	5A
4	M	L	5A
4	M	M	5A
4	M	H	5A
4	H	L	5A
4	H	M	5A
4	H	H	5A
6	L	L	(a)
6	L	M	5A
6	L	H	5A
6	M	L	(a)
6	M	M	5A
6	M	H	5A
6	H	L	(a)
6	H	M	5A
6	H	H	(b)

(a) - Too thick to test
(b) - Too thin to test
*** - Adhesion Rating

5A - no peeling or removal
4A - trace removal or peeling along cuts
3A - jagged removal along cuts up to 1/16" on either side
2A - jagged removal along cuts up to 1/8" on either side
1A - removal from most of the area of the x under tape
0A - removal beyond the x area

Table 2D: Results of Adhesion Testing, Phase 2
(Composite Mix)

Source	Additive	Water	Sand	Adhesion Rating
1	L	L	L	5A
1	L	M	L	5A
1	L	H	L	5A
1	L	L	H	5A+
1	L	M	H	5A+
1	L	H	H	(b)
1	M	L	L	5A
1	M	M	L	5A+
1	M	H	L	5A
1	M	L	H	5A
1	M	M	H	5A+
1	M	H	H	5A+
1	H	L	L	(a)
1	H	M	L	(a)
1	H	H	L	(a)
1	H	L	H	(a)
1	H	M	H	(a)
1	H	H	H	(a)
2	L	L	L	5A
2	L	M	L	5A
2	L	H	L	(b)
2	L	L	H	5A+
2	L	M	H	5A+
2	L	H	H	5A
2	M	L	L	5A
2	M	M	L	5A
2	M	H	L	5A+
2	M	L	H	5A
2	M	M	H	5A+
2	M	H	H	5A+
2	H	L	L	5A
2	H	M	L	5A
2	H	H	L	(b)
2	H	L	H	5A+
2	H	M	H	5A+
2	H	H	H	(b)

Table 2D: Results of Adhesion Testing, Phase 2
(Composite Mix) (Continued)

Source	Additive	Water	Sand	Adhesion Rating
3	L	L	L	5A
3	L	M	L	5A
3	L	H	L	5A
3	L	L	H	5A+
3	L	M	H	5A+
3	L	H	H	5A
3	M	L	L	5A
3	M	M	L	5A+
3	M	H	L	5A
3	M	L	H	(a)
3	M	M	H	5A
3	M	H	H	5A+
3	H	L	L	5A
3	H	M	L	(b)
3	H	H	L	(b)
3	H	L	H	5A
3	H	M	H	(b)
3	H	H	H	(b)
4	L	L	L	5A
4	L	M	L	5A
4	L	H	L	5A
4	L	L	H	5A+
4	L	M	H	5A+
4	L	H	H	4A+
4	M	L	L	5A
4	M	M	L	5A
4	M	H	L	5A
4	M	L	H	5A
4	M	M	H	4A+
4	M	H	H	5A+
4	H	L	L	5A
4	H	M	L	5A
4	H	H	L	5A
4	H	L	H	(a)
4	H	M	H	4A+
4	H	H	H	5A+

Table 2D: Results of Adhesion Testing, Phase 2 (Composite Mix) (Continued)

Source	Additive	Water	Sand	Adhesion Rating
6	L	L	L	(a)
6	L	M	L	5A
6	L	H	L	5A
6	L	L	H	(a)
6	L	M	H	4A+
6	L	H	H	5A+
6	M	L	L	(a)
6	M	M	L	5A
6	M	H	L	5A
6	M	L	H	(a)
6	M	M	H	(a)
6	M	H	H	5A
6	H	L	L	(a)
6	H	M	L	4A
6	H	H	L	(b)
6	H	L	H	(a)
6	H	M	H	4A
6	H	H	H	(b)

(a) - Too thick to test
(b) - Too thin to test
\+ - Sand removal by tape

APPENDIX G
FUEL RESISTANCE TEST DATA

Additive

L = Low (4.0 gal/100 gal CT)
M = Medium (14.5 gal/100 gal CT)
H = High (25 gal/100 CT)

Water

L = Low (20 gal/100 CT)
M = Medium (55 gal/100 gal CT)
H = High (90 gal/100 gal CT)

Sand

L = Low (2 lbs/gal CT)
H = High (13 lbs/gal CT)

Table 1E: Kerosene Resistance Results, Phase 1 (Composite System)

Source	Additive	Water	Sand	Sand Type (R,A)	Sand Grad (F,C)	Tile Test (P/F)
1	H	H	L	A	C	(a)
1	H	H	L	R	F	(a)
1	H	H	H	A	F	(a)
1	H	H	H	R	C	(a)
1	L	L	L	A	C	Pass
1	L	L	L	R	F	Pass
1	L	L	H	A	F	Pass
1	L	L	H	R	C	Pass
1	H	L	H	A	C	(a)
1	H	L	H	R	F	(a)
1	H	L	L	A	F	(a)
1	H	L	L	R	C	(a)
1	L	H	H	R	F	Fail
1	L	H	H	A	C	Fail
1	L	H	L	R	C	Pass
1	L	H	L	A	F	Pass
2	H	H	L	A	C	Pass
2	H	H	L	R	F	Pass
2	H	H	H	A	F	Pass
2	H	H	H	R	C	Pass
2	L	L	L	A	C	Pass
2	L	L	L	R	F	Pass
2	L	L	H	A	F	Pass
2	L	L	H	R	C	Pass
2	H	L	H	A	C	Pass
2	H	L	H	R	F	Pass
2	H	L	L	A	F	Pass
2	H	L	L	R	C	Pass
2	L	H	H	R	F	(b)
2	L	H	H	A	C	(b)
2	L	H	L	R	C	(b)
2	L	H	L	A	F	(b)

Table 1E: Kerosene Resistance Results, Phase 1 (Composite System) (Continued)

Source	Additive	Water	Sand	Sand Type (R,A)	Sand Grad (F,C)	Tile Test (P/F)
3	H	H	L	A	C	(b)
3	H	H	L	R	F	(b)
3	H	H	H	A	F	(b)
3	H	H	H	R	C	(b)
3	L	L	L	A	C	Pass
3	L	L	L	R	F	Pass
3	L	L	H	A	F	Pass
3	L	L	H	R	C	Fail
3	H	L	H	A	C	Fail
3	H	L	H	R	F	Fail
3	H	L	L	A	F	Pass
3	H	L	L	R	C	Fail
3	L	H	H	R	F	Pass
3	L	H	H	A	C	Pass
3	L	H	L	R	C	Pass
3	L	H	L	A	F	Fail
4	H	H	L	A	C	Pass
4	H	H	L	R	F	Pass
4	H	H	H	A	F	Pass
4	H	H	H	R	C	Pass
4	L	L	L	A	C	Fail
4	L	L	L	R	F	Pass
4	L	L	H	A	F	Pass
4	L	L	H	R	C	Fail
4	H	L	H	A	C	(a)
4	H	L	H	R	F	(a)
4	H	L	L	A	F	(a)
4	H	L	L	R	C	(a)
4	L	H	H	R	F	Pass
4	L	H	H	A	C	Fail
4	L	H	L	R	C	Pass
4	L	H	L	A	F	Fail

Table 1E: Kerosene Resistance Results, Phase 1
(Composite System) (Continued)

Source	Additive	Water	Sand	Sand Type (R,A)	Sand Grad (F,C)	Tile Test (P/F)
5	H	H	L	A	C	(b)
5	H	H	L	R	F	(b)
5	H	H	H	A	F	(b)
5	H	H	H	R	C	(b)
5	L	L	L	A	C	Pass
5	L	L	L	R	F	Pass
5	L	L	H	A	F	Pass
5	L	L	H	R	C	Pass
5	H	L	H	A	C	Pass
5	H	L	H	R	F	Pass
5	H	L	L	A	F	Fail
5	H	L	L	R	C	Fail
5	L	H	H	R	F	Fail
5	L	H	H	A	C	Fail
5	L	H	L	R	C	Pass
5	L	H	L	A	F	Fail

(a) - Too thick to test
(b) - Too thin to test

Table 2E: Wet Track Abrasion Results, Phase 2
Coal Tar Source 1

Sample Number	Application Rate (gal/yd2)	Weight applied to abrasion surface, (g)	Weight inc. or dec. (g)	Percent inc. or dec.
46				
b	0.12	12.89	0.80	0.04 *
c	0.10	10.68		**
78				
a	0.19	26.04	-70.80	-3.28 **
b	0.17	23.01	-42.80	-1.98
c	0.20	28.38	-43.40	-2.07
83				
a	0.08	8.37	2.70	0.14 **
b	0.11	11.73	4.40	0.21 **
c	0.08	8.17	7.70	0.39
72				
a	0.15	18.05	-17.00	-0.75
b	0.09	10.88	-4.80	-0.24
c	0.09	10.80	-5.10	-0.26

* - Sample was soft after WTAT
** - Sample fell apart after WTAT

Table 2E: Wet Track Abrasion Results, Phase 2
Coal Tar Source 2

Sample Number	Application Rate (gal/yd2)	Weight applied to abrasion surface, (g)	Weight inc. or dec. (g)	Percent inc. or dec.
36				
a	0.11	9.34	1.80	0.09 *
b	0.10	11.08	3.20	0.16 *
c	0.06	6.71	11.00	0.55 *
77				
a	0.21	30.37	10.30	0.51 *
b	0.19	28.32	4.30	0.20 **
c	0.19	27.98	17.70	0.84 *
47				
a	0.02	2.03		**
b	0.05	4.48	125.60	6.36 **
c	0.03	2.95	3.70	0.19 *
84				
a	0.08	8.60	118.60	6.24 **
b	0.08	8.49	-124.60	-5.92 **
c	0.07	7.02	-3.30	-0.16

* - Sample was soft after WTAT
** - Sample fell apart after WTAT

Table 2E: Wet Track Abrasion Results, Phase 2
Coal Tar Source 2

Sample Number	Application Rate (gal/yd2)	Weight applied to abrasion surface, (g)	Weight inc. or dec. (g)	Percent inc. or dec.
36				
a	0.11	9.34	1.80	0.09 *
b	0.10	11.08	3.20	0.16 *
c	0.06	6.71	11.00	0.55 *
77				
a	0.21	30.37	10.30	0.51 *
b	0.19	28.32	4.30	0.20 **
c	0.19	27.98	17.70	0.84 *
47				
a	0.02	2.03		**
b	0.05	4.48	125.60	6.36 **
c	0.03	2.95	3.70	0.19 *
84				
a	0.08	8.60	118.60	6.24 **
b	0.08	8.49	-124.60	-5.92 **
c	0.07	7.02	-3.30	-0.16

* - Sample was soft after WTAT
** - Sample fell apart after WTAT

Table 2E: Wet Track Abrasion Results, Phase 2 (Continued)
Coal Tar Source 3

Sample Number	Application Rate (gal/yd2)	Weight applied to abrasion surface, (g)	Weight inc. or dec. (g)	Percent inc. or dec.
55				
a	0.12	12.10	-2.60	-0.13
b	0.12	12.13	3.80	0.19 *
c	0.09	10.10	2.30	0.11 *
43				
a	0.08	8.00	-3.80	-0.19
b	0.11	10.82	3.70	0.19 *
c	0.11	11.01	-1.40	-0.07 *
59				
a	0.15	18.97	9.20	0.42 *
c	0.12	15.52	-20.30	-1.02 *

* - Sample was soft after WTAT
** - Sample fell apart after WTAT

Table 2E: Wet Track Abrasion Results, Phase 2 (Continued)
Coal Tar Source 6

Sample Number	Application Rate (gal/yd2)	Weight applied to abrasion surface, (g)	Weight inc. or dec. (g)	Percent inc. or dec.
87				
a	0.08	8.17	-1.30	-0.06
b	0.08	8.06	-47.10	-2.38
c	0.05	4.04	4.50	0.23
89				
a	0.15	18.55	-18.80	-0.89
b	0.13	15.46	-17.10	-0.81
c	0.10	12.79	-8.40	-0.40

Table 2E: Wet Track Abrasion Results, Phase 2 (Continued)
Coal Tar Source 4

Sample Number	Application Rate (gal/yd2)	Weight applied to abrasion surface, (g)	Weight inc. or dec. (g)	Percent inc. or dec.
22				
a	0.09	9.61	6.90	0.33 *
b	0.08	8.09	16.10	0.88 *
c	0.08	8.60	7.60	0.36 *
56				
a	0.15	22.23	186.60	9.73 ***
b	0.16	23.33	-16.70	-0.76 ***
c	0.13	19.51	-17.10	-0.83 ***
88				
a	0.06	5.78	-3.10	-0.16 *
b	0.07	6.64	-4.40	-0.22 *
c	0.07	6.79	3.60	0.18 *
86				
a	0.09	11.82	1.20	0.06 **
b	0.08	10.92	2.90	0.14 *
c	0.10	12.53	4.00	0.21 **

* - Sample was soft after WTAT
** - Sample fell apart after WTAT
*** - Coating peeled off sample

Table 2E: Wet Track Abrasion Results, Phase 2 (Continued)
Coal Tar Source 6

Sample Number	Application Rate (gal/yd2)	Weight applied to abrasion surface, (g)	Weight inc. or dec. (g)	Percent inc. or dec.
87				
a	0.08	8.17	-1.30	-0.06
b	0.08	8.06	-47.10	-2.38
c	0.05	4.04	4.50	0.23
89				
a	0.15	18.55	-18.80	-0.89
b	0.13	15.46	-17.10	-0.81
c	0.10	12.79	-8.40	-0.40